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SUPERGENE AND HYDROTHERMAL DISPERSION OF HEAVY METALS IN WALL ROCKS NEAR ORE BODIES, TINTIC DISTRICT, UTAH.[1]

H. T. MORRIS AND T. S. LOVERING.

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[1] Publication authorized by the Director, U. S. Geological Survey.

ABSTRACT.

PART I, T. S. LOVERING.

Preliminary work in the Tintic district, Utah, determined the relative distance of migration of ore metals in moist carbonate and silicic wall rocks near ore, and in ground water having a very sluggish circulation through mineralized ground. The analyses of efflorescences in the Tintic Standard mine openings at suitable localities indicated that under the conditions existing during the past 25 years lead has not moved perceptibly; gold has migrated only a few inches; copper has moved a few score feet at most and only in acid solutions; and zinc has traveled hundreds of feet, but not as far as some silver. Silver may travel far in the oxidized zone, but if it comes in contact with sulfides its migration is quickly halted.

The chief chemical factors that influence the migration of metals in supergene solutions are the hydrogen ion concentration (pH) of hydrolysis of the metal ion, the solubility of sulfates of the metals, and the position of the metals in Schuermann's series if the solutions are in contact with sulfides for a considerable time.

PART II, H. T. MORRIS.

Primary dispersion gradients of lead, copper, and zinc, slightly modified by supergene solutions locally, have been recognized in the Tintic district, Utah, in hydrothermally altered wall rocks of gold- and silver-bearing lead-zinc-copper veins in monzonite and in dolomite near lead-zinc replacement ore bodies.

The metal content of the rocks near ore seems to decrease logarithmically, and the plotted curves strongly suggest diffusion; the precipitation in the wall rocks at a short distance from the ore must have entailed a concomitant drop in concentration of the metal ions in the mineralizing solution, which in turn would tend to maintain the initial concentration gradient. The curves indicate a short-lived source.

Evidence was found of supergene leaching and precipitation of zinc in the wall rocks near ore bodies in the oxidized zone above the water table, but lead is apparently static under surface conditions and reflects primary dispersion patterns. Copper appears to be relatively stable in a carbonate environment, but moves locally in hydrothermally altered monzonite.

The dispersion patterns of lead in the oxidized zone—and locally the patterns of zinc and copper as well—are similar to those adjacent to primary sulfide ore bodies 700 feet below the water table and 2,600 feet below the surface.

PART I.

MOBILITY OF HEAVY METALS IN GROUND WATER.

T. S. LOVERING.

INTRODUCTION.

THE large amount of geochemical work that has been done in many countries includes numerous studies of the dispersion patterns of metals in glacial sediments, soils, ground water, alluvium, and vegetation; but it includes a few studies on the relation of traces of heavy metals in wall rocks of ore deposits to the presence of adjacent ore bodies or to blind ore bodies. All these studies have been primarily concerned with geochemical prospecting as a

method of discovering concealed ore bodies. It seems important, however, to discover the extent to which metals are introduced into the wall rocks of ore bodies, the probable mechanism of introduction, and the implications that the dispersion patterns may have to the genesis of the ore bodies themselves. The practical significance of the pattern in the discovery of ore can also be better appraised after such studies are made.

In 1947 a program of geochemical investigations by the U. S. Geological Survey was started in the Tintic and East Tintic districts, Utah, to accumulate fundamental information on the distribution of heavy metals in fresh and altered rock and their mobility in supergene and hydrothermal solutions. A substantial amount of data was accumulated from which certain deductions and inferences can be made, but unfortunately the program was interrupted before completion by diversion of the chemical personnel to work that seemed of more immediate practical importance. Probably the work necessary to a thoroughly satisfactory solution of the problems will not be carried out, but it seems desirable to present the information now at hand and the tentative conclusions reached.

The mobility of metals in acid mine waters has been studied in past years by many investigators, but little work has been done on the migration of heavy metals through moist zones where the circulation of water was sluggish or nonexistent. As moist rock, rather than water channels, accounts for the mobility of metals at the surface within rock of low permeability, this was the environment that was studied in the preliminary investigation designed to orient the writers in selecting and interpreting the areas to be investigated near ore deposits at the surface in the Tintic district. Efflorescences and stalactites that had formed in the galleries of the Tintic Standard mine over a period of many years were collected in both the oxide and sulfide zones from areas chosen so far as possible to emphasize the effects of the distance that the materials would migrate from the known sources of the metals. These collections were examined by the writers and analyzed by Mr. Christopher A. Schempp, the excellent analytical chemist then employed by the Tintic Standard Mining Co. Identification of the secondary minerals was in part megascopic recognition of common minerals and in part microscopic determinations in which immersion oils were used; both methods were checked against the partial analyses made by Mr. Schempp.

The efflorescences in the Tintic Standard mine were analyzed by the standard methods used in assay laboratories and are not to be compared with the trace analysis methods that were used for the rest of the work and that were designed to detect a few parts of metal per million of sample. The accuracy of the wet methods of analysis used for lead, zinc, and copper is sufficient for satisfactory determination of the metals in efflorescences; a precision of a few parts per million in the analysis of material collected in old drifts would be meaningless. The fire assays for gold and silver are accurate to less than 0.01 oz. per short ton of sample, or about 0.3 ppm.

The second step in the investigation included the selection and sampling of outcrop areas near fissure veins in hydrothermally altered monzonite that was originally uniform in composition, the determination of Cu, Pb, and Zn, in

parts per million in the sample, and the interpretation of the results. Similar studies were then made adjacent to narrow ore bodies in dolomites, and were followed by work next to sulfide stopes some 2,600 feet below the sampled outcrop and well below the water level. The work on the mobility of the various heavy metals that was carried on in the Tintic Standard mine enabled the writers to discriminate between supergene and hypogene effects in the dispersion pattern of the metals at the surface; these results were checked by the small amount of work done below water level before the work was terminated in midsummer of 1949.

ACKNOWLEDGMENTS.

The analytical work carried out by Mr. Schempp was made possible by a grant from the Geological Society of America, whose generosity the writers acknowledge with thanks.

The determinations of minute amounts of heavy metals disseminated in the wall rocks near ore bodies in the main Tintic district were made by Mr. Hy Almond, of the U. S. Geological Survey, and the writers are happy to pay tribute to his careful, consistently accurate work. Appreciation is also expressed for the friendly cooperation extended by the Tintic Standard Mining Co. and the Chief Consolidated Mining Co. in giving permission to study and collect materials from any of their mine openings. The intimate knowledge of the Tintic Standard mine acquired by Mr. Ernest Boyne during long years of residence was cordially placed at the disposal of the writers and made it possible to gather specimens whose value was immeasurably enhanced by Mr. Boyne's instant and accurate knowledge of the location of nearby ore shoots, and also made it possible to go directly to suitable localities underground that might otherwise have been overlooked. Similarly, the intimate knowledge of the geology of the Chief No. 1 mine that Mr. William G. Stevenson had acquired through careful mapping of the lower workings made it possible to select the best areas for study with the minimum expenditure of time and effort on the part of the writers; this help was greatly appreciated.

MOBILITY OF METALS IN GROUND WATER, TINTIC STANDARD MINE.

General Considerations.—The mobility of any metal in ground water or moist rock is a function of the hydrogen ion concentration of the environment, the chemical character of the solution, the chemical character of the wall rocks, and the rate of movement of the solution through the rocks. In the vicinity of ore bodies the ground water above the water table is commonly characterized by a high proportion of carbonate and bicarbonates in the oxidized zone and an increasing proportion of acid sulfates with depth. The hydroxides of most metals are comparatively insoluble and therefore the pH at which hydrolysis takes place may be of major importance in determining the mobility of metals. The hydrogen ion concentration of a dilute water solution may range from 10^{-7} (pH 7) at the neutral point (pure water) to approximately 10^{-1} (pH 1) for 0.10 *N* mineral acids. The pH of an acid of this strength can obviously be changed from pH 1 to approximately pH 7

(neutrality) by the simple method of dilution, and dilution is a major factor in determining solution or precipitation of some metallic compounds in the environment of oxidizing ore bodies. The change in pH caused by contact of acid solutions with reactive alkaline rocks such as limestone and dolomite is a well recognized cause of precipitation in the vadose zone, but the effects of dilution are less generally known. The pH at which precipitation by hydrolysis takes place for a few of the more common metallic elements is given in the table below:

TABLE 1.

pH OF SOLUTIONS AT WHICH VARIOUS INSOLUBLE METALLIC COMPOUNDS BEGIN TO PRECIPITATE, AND SOLUBILITY OF SOME COMMON SULFATES (1).[2]

Metal	pH	Metal	pH	Metal	pH
Hydroxides.					
Mg	10.5	Co	6.8	U(ic)	4.2
Mn(ous)	8.5–8.8	Ni	6.7	Al	4.1
Ag	7.5–8.0	Cd	6.7	Hg(ous)	3.0
Hg(ic)	7.3	Fe(ous)	5.5	Th	3.5
Zn	5.3–6.8	Cu(ic)	5.3	Sn(ous)	2.0
Pb	6.8	Cr(ic)	5.3	Fe(ic)	2.0
Basic carbonates.					
Mg	10.5	Zn	5.3	Al	4.2
Mn(ous)	8.7	Cr	5.3	Th	3.4
Basic silicates.					
Ca	10.1	Mn	7.4	Al	4.1
Mg	9.5	Ag	5.3	Th	3.5
Normal or basic phosphates.					
Mg	9.8	Mn(ous)	5.8	Al	3.8
Ca	7.0	Zn	5.7	Th	2.7

Solubility of sulfates in grams per 100 grams H_2O, 25°C.

Metal	pH	Metal	pH
$PbSO_4$	0.0042	$CuSO_4 \cdot 5H_2O$	18.47
Ag_2SO_4	0.57	$ZnSO_4 \cdot 7H_2O$	96.5
$FeSO_4 \cdot 7H_2O$	15.65	$Fe_2(SO_4)_3 \cdot 9H_2O$	440.0

[2] Numbers in parentheses refer to Bibliography at end of paper.

Britton (1) has shown that the precipitation pH of the metal hydroxide is commonly influenced but little by the acid radical (Table 1), and that changes in concentration cause only a small difference between the pH at which precipitation commences and the pH at which it is complete. This range is usually less than 1 pH unit. It should be noted, however, that certain

anions, such as fluorine, may form a complex ion or molecule that does not precipitate by hydrolysis; still another factor that modifies simple hydrolysis is the formation of basic salts (as with basic carbonates or basic sulfates), which precipitate at a lower pH than the hydroxides.

Although the pH of a solution is important in determining the precipitation of the relatively insoluble hydroxides, carbonates, silicates, and phosphates of the metals, some of the metals form insoluble compounds with certain anions in solutions much more acid than the precipitation points noted in Table 1 (2). Lead sulfate is nearly insoluble in relatively acid solutions but lead carbonate is readily soluble at a pH of 5, and can migrate far in solutions of organic acids if they are free from sulfates. Silver chloride and silver sulfide are extremely insoluble, but silver sulfate or silver bicarbonate can persist in chloride-free solutions of relatively high pH as long as they are not in contact with sulfides. Gold salts are so unstable in the presence of ferrous salts that gold would be expected to travel only very short distances in ferrous sulfate solutions. Although both the zinc ion and the cupric ion (Cu^{II}) start to precipitate at a pH of 5.3, the zinc is not completely precipitated until a pH of 6.8 is reached, whereas the cupric ion is completely precipitated before the solution reaches a pH of 5.7; the cuprous ion (Cu^{I}) is unstable during hydrolysis and precipitates as cuprous oxide at a much lower pH, but the presence of any ferric salt oxidizes the cuprous ion to the cupric ion immediately. In contrast, zinc is stable in acid solutions as sulfate, chloride, or bicarbonate to the pH of hydrolysis at 5.3. Zinc salts may be precipitated by reaction with carbonates in the pH range of its hydrolysis, but is not precipitated by sulfides; therefore it should be the most migratory of the five metals studied.

The pH of ground water that enters the oxidized ore zone is slightly less than 7 and does not decrease (become more acid) until the ground water comes in contact with oxidizing sulfides and starts to acquire soluble sulfates and sulfuric acid. While in the sulfide environment, the precipitation of metals from supergene acid solutions is controlled chiefly by the relative solubility of the metal sulfides—the Schuermann series (2)—but after passing into a carbonate or quartzose country rock, the relative pH of hydrolysis of the metals becomes increasingly important. In areas of jasperoid and quartzite the acids persist for some distance from the site of their generation, but in dolomite and limestone country rock the acids are soon neutralized. The insolubility of lead sulfate, the ready reduction of gold, and the differing pH of hydrolysis of the metals suggest that as solutions change from a low pH toward the neutral point during their migration away from an oxidizing ore body into reactive country rock or into zones where dilution occurs the metals would drop out in approximately the following order: lead and gold almost at once; ferric iron very shortly, ferrous iron and copper next, and zinc and silver at greater distances.

Study of Table 1 suggests that efflorescences containing iron in the ferric state are formed through the evaporation of relatively acid solutions. Aluminum, which is amphoteric, can travel in solution only if its environment is at a pH less than 4.1 or greater than 9. The beautiful purple and blue ferric

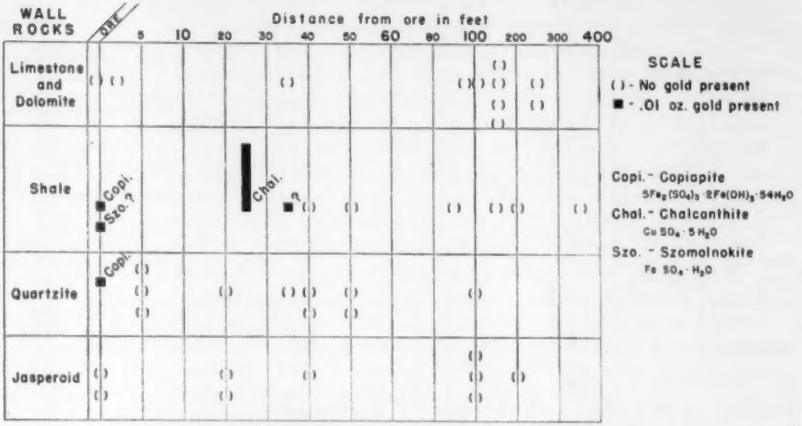


FIG. 1. Gold content of leach minerals, Tintic Standard mine, East Tintic district, Utah.

sulfate, coquimbite, is common under ore bodies in quartzite walls, but was not seen on dolomite and limestone. Coquimbite was not observed in pyritic shale; instead, the nearly white aluminum-iron sulfate halotrichite and its dehydration alteration product, szomolnokite, are common. The bright yellow basic ferric sulfate copiapite, however, which is most common in quartzite walls at a distance from ore bodies, is also found coating pyritic shales and oxidizing pyritic ore; it is relatively rare in an environment of dolomite and

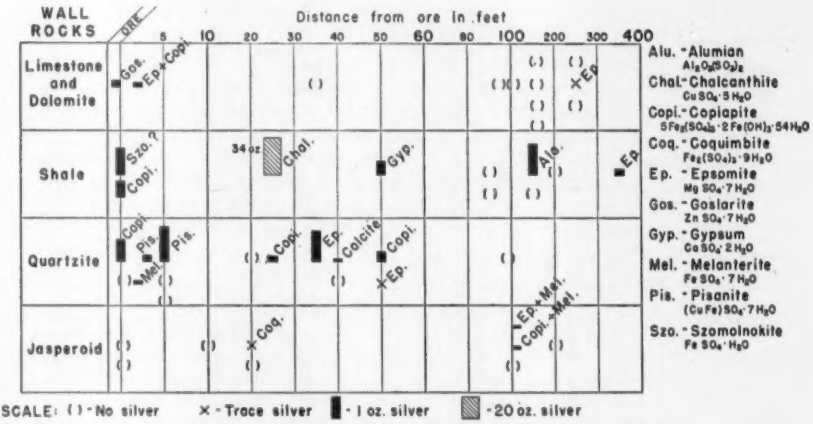


FIG. 2. Silver content of leach minerals, Tintic Standard mine.

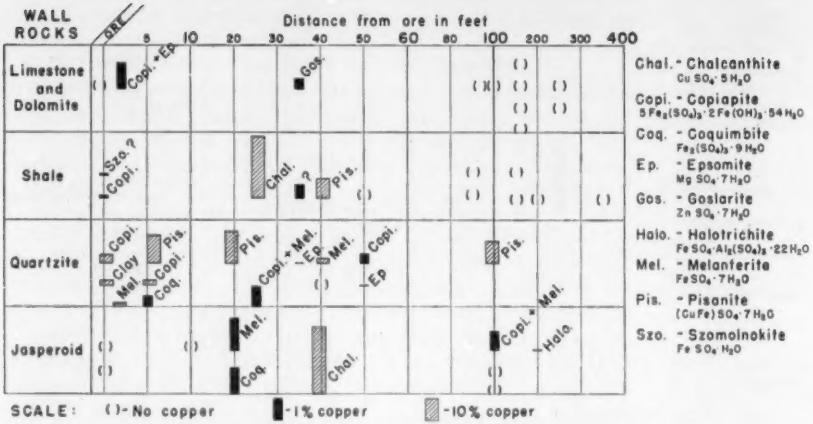


FIG. 3. Copper content of leach minerals, Tintic Standard mine.

limestone but is occasionally found on these rocks. The magnesium sulfate, epsomite, in contrast, characteristically coats drifts in dolomite but is also found on quartzite walls beneath ore bodies and may be found far from sulfide ores, as it can travel in solutions of relatively high pH. As it crystallizes from solutions that are concentrated by evaporation, the epsomite forms wherever the magnesium solutions evaporate, both at substantial distance from any known oxidizing pyrite and close to such sources of sulfate solution, especially where pyritic shales are in contact with dolomite, the source of the magnesium.

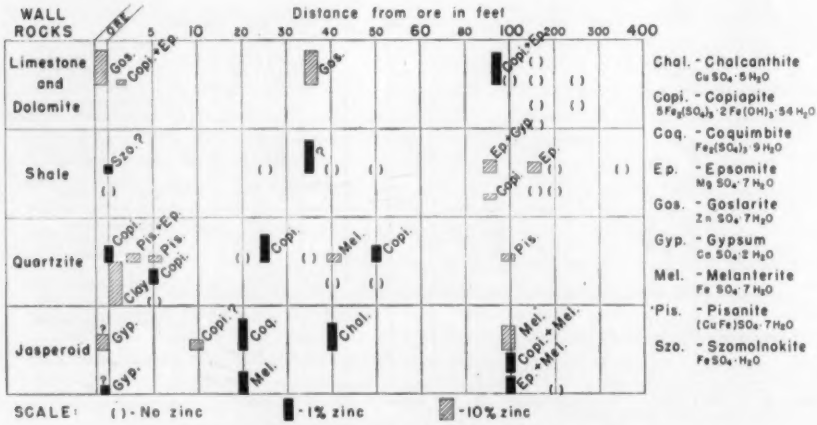


FIG. 4. Zinc content of leach minerals, Tintic Standard mine.

Leach Minerals of the Tintic Standard Mine.—In the vicinity of oxidizing ores in the Tintic Standard mine the waters are typical acid sulfate waters, with relatively low pH, but the moisture seeping out of cracks at some distance from the oxidizing ores has a pH of approximately 7 or somewhat greater. Most of the specimens for study were collected in drifts where no moisture was apparent; it is only the presence of the soluble sulfates along relatively tight cracks that betrays the presence of moisture. Wherever visible water is present the form of the evaporites is quite different from the cottony effloresences in the relatively dry environment referred to above. Salts deposited from visible water most commonly take the form of stalactites or stalagmites, and in a few places form scaly coatings on the sides of the drift.

The composition of the sulfates formed by evaporation of moisture in the underground openings of the Tintic Standard mine is given in Table 2, and the analyses of the efflorescences and the stalactites are given in Table 3. The general relations of composition and mineralogy are shown in Figures 1 to 4. The movement of the various metals found in these salts seems to be in harmony with the chemical considerations discussed earlier.

It is beyond the scope of this paper to discuss the conditions of formation of the various individual sulfates, but this problem is treated at length in a report by Lovering, Morris, and others, entitled Geology, alteration, and ore deposits of the East Tintic district, Utah, which is to be published by the U. S. Geological Survey. For excellent discussions of the phase relations and occurrence of iron and copper sulfates, the reader is referred to other articles (3, 5, 6, 7, 9).

Gold.—As shown in Table 3, none of the specimens of efflorescences in the carbonate rocks contained any gold, but several of those collected in shale contained an appreciable amount (Fig. 1). Gold was found as far as 35 feet from its source and the highest assay (0.08 ounce per ton) was in chalcanthite in shale walls 25 feet below an ore body. Copiapite and specimens of a dehydrated white mineral that may have been szomolnokite were the other auriferous leach minerals in shale. Copiapite and pisanite were the two leach minerals that carried gold in the quartzite, but the gold-bearing specimens were confined to a zone less than 5 feet from the source of the gold. The affinity of gold for the cupric sulfate solutions is indicated by its presence in chalcanthite and pisanite; its presence in copiapite suggests acid ferric sulfate solutions, with iron just starting to hydrolyze. The pisanite is at the 1,450 level of the mine directly under a substantial amount of sulfide ore and was collected close to a fissure that was mineralized with copper and gold.

Silver.—Silver is distributed sporadically in the leach minerals (Fig. 2), but was found in otherwise barren epsomite as much as 350 feet from the nearest known ore, more than twice the distance recorded for zinc in the same mineral—and zinc is the second most ambulatory metal. The highest silver assay—34 ounces per ton—was for the chalcanthite that also had the highest gold content of any leach mineral. As shown in Table 3, however, amounts ranging from a trace to 2½ ounces per ton were present in many leach minerals; silver was present in some specimens of every variety of leach mineral collected. It was the only metal found in calcite and in white gypsum.

TABLE 2.

SOLUBLE SULFATES OF THE TINTIC STANDARD MINE.

Iron sulfates.

Rhomboclase $H\,Fe(SO_4)_2 \cdot 4H_2O$ (Fe_2O_3 24.9; SO_3 49.9; H_2O 25.2)
Kornelite $Fe_2(SO_4)_3 \cdot 7H_2O$ (Fe_2O_3 30.0; SO_3 45; H_2O 25)
Coq Coquimbite $Fe_2(SO_4)_3 \cdot 9H_2O$ (Fe_2O_3 28.5; SO_3 42.7; H_2O 28.8)
Copi Copiapite $(Mg, Cu, Fe^{II}, Fe^{III})\,Fe_4^{III}\,(SO_4)_6 \cdot (OH)_2 \cdot 20H_2O$ (Fe_2O_3 29.1; SO_3 36.4; H_2O 34.5)
Bilinite $Fe^{II}Fe_4^{III}\,(SO_4)_4 \cdot 22H_2O$
Roemerite $Fe^{II}Fe_2^{III}\,(SO_4)_4 \cdot 14H_2O$ (Fe_2O_3 20.8; FeO 9.4; SO_3 41.7; H_2O 28.1)
Vol Voltaite $(K, Fe^{II}) \cdot (Al, Fe^{III}) \cdot (SO_4)_3 \cdot (OH) \cdot 5H_2O$ (Fe_2O_3 13; FeO 15; H_2O 16)
Halo Halotrichite $Fe^{II}Al\,(SO_4)_3 \cdot 22H_2O$ (FeO 7.8; Al_2O_3 11.0; SO_3 34.5; H_2O 46.7)
Szo Szomolnokite $FeSO_4 \cdot H_2O$ (FeO 42.3; SO_3 47; H_2O 10.6)
Siderotil $FeSO_4 \cdot 4H_2O$ (FeO 32.10; SO_3 35.80; H_2O 32.10)
Mel Melanterite $FeSO_4 \cdot 7H_2O$ (FeO 25.9; SO_3 28.8; H_2O 45.8)

Zinc sulfates.

Gos Goslarite $ZnSO_4 \cdot 7H_2O$ (ZnO 28.2; SO_3 27.0; H_2O 43.9) May contain iron (ferroan goslarite) or copper (cuproan goslarite) and these intergrade through zinc-copper melanterite

Copper sulfates.

Chal Chalcanthite $CuSO_4 \cdot 5H_2O$ (CuO 31.8; SO_3 32.1; H_2O 36.1)
Pis Pisanite $(Fe^{II}, Cu)SO_4\,7H_2O$ (FeO ±11; CuO ±15; SO_3 ±30; H_2O ±44)

Magnesium sulfates.

Ep Epsomite $MgSO_4 \cdot 7H_2O$ (MgO 16.3; SO_3 32.5; H_2O 51.2)
Kieserite $MgSO_4 \cdot H_2O$ (MgO 29.0; SO_3 48.0; H_2O 13.0)

Calcium sulfate.

Gyp Gypsum $CaSO_4 \cdot 2H_2O$ (CaO 32.5; SO_3 46.6; H_2O 20.9)

Aluminum sulfates.

Alu Alumian $Al_2O_3(SO_3)_3$ (Al_2O_3 39.9; SO_3 60.1)

Spec. no. + level	Coordinates	Mineralogy	Environment	Distance from ore	Au	Ag	Cu	Pb	Zn	H_2O
28–14	23,320 E 33,153 N	Coq	Pyritic sheeted zone, qzt. Moist	5 ft	.00	.00	.50	.0	.0	22.96
29–14	23,320 E 33,153 N	Copi	Pyritic sheeted zone, qzt. Slightly moist	5 ft	.00	.00	2.30	.0	.7	27.98
30–14	23,320 E 33,153 N	Pis	Pyritic sheeted zone, qzt. Moisture	5 ft	.02	1.6	13.28	.0	2.1	31.76
31–7	23,693 E 33,848 N	Chal	Tight fiss, qtz. No moisture	20 ft	.00	.00	15.20	.0	.0	17.0
32–8	23,725 E 33,725 N	Copi + Mel	Tight jointed qzt. No moisture	25 ft	.00	.25	.94	.0	1.2	21.50
33–8	23,674 E 33,750 N	Ep	Tight jointed qtz. No moisture	35 ft	.00	1.40	.05	.0	.0	37.46
34–9	23,642 E 33,607 N	Zn, Cu, Mel	Fiss qzt. No moisture	40 ft	.00	.00	2.34	.0	3.2	40.81
35–8	23,740 E 33,718 N	Calcite	Tight jointed qzt. No moisture	40 ft	.00	.10	.00	.0	.0	18.66
36–9	23,642 E 33,607 N	Copi	Tight fract. qzt. Slight moisture	50 ft	.00	.45	.44	.0	.7	26.37
37–9	23,642 E 33,607 N	Ep(?)	Tight fract qzt. Slightly moist	50 ft	.00	tr	.15	.0	.0	38.84
38–14	23,235 E 33,245 N	Pis	Slightly fract qzt. Moisture	100 ft	.00	.00	10.36	.0	3.3	35.83

TABLE 2.—*Continued.*

Spec. no. + level	Coordinates	Mineralogy	Environment	Distance from ore	Au	Ag	Cu	Pb	Zn	H_2O
			Jasperoid wall rocks							
39–9	23,515 E 33,670 N	Blk, Gyp(?)	Flt, jasp+ore. No moisture	Adjac	.00	.00	.00	.5	.4	9.56
40–9	23,294 E 33,690 N	Blk, Gyp(?)	Flt, jasp+ore. No moisture	Adjac.	.00	.00	.00	7.3	7.2	14.46
41–12	23,325 E 33,330 N	Dehyd., Cop(?)	Fract min jasp	10 ft	.00	.00	.00	.6	4.1	3.41
42–12	23,158 E 33,310 N	Zn, Cu, Coq	Frac jasp. No moisture	20 ft from low grade	.00	tr	1.20	.0	1.4	15.88
43–12	23,173 E 33,300 N	Mel	Fract jasp. Slightly moist	20 ft	.00	.00	1.54	.0	1.0	38.32
14–12	23,395 E 33,360 N	Chal	Fract sh. sltly silic. No moisture	25 ft below	.08	34.00	28.36	.0	.0	23.61
15–8	33,764 E 23,513 N	?	Tight flt, sh. No moisture	35 ft	.01	2.60	.64	.0	1.5	7.35
16–8	23,517 E 33,770 N	Pis	Op. flt, sh+qzt. No moisture	40 ft	.00	5.0	8.92	.0	.0	11.26
17–8	23,505 E 33,763 N	Gyp	Tight fract, alt sh+jasp. No moisture	50 ft	.00	.65	.00	.0	.0	21.30
18–8	23,475 E 33,755 N	Gyp +Ep	Tight fract, alt sh+jasp. No moisture	90 ft	.00	.00	.00	.0	5.8	18.53
19–8	23,475 E 33,755 N	Copi	Tight fract, alt sh+jasp. No moisture	90 ft	.00	.00	.00	.0	2.0	10.75
20–8	23,386 E 33,790 N	Ep	Shrd sh. H.W. ore fiss. No moisture	150 ft	.00	.00	.00	.0	5.3	40.32
21–8	23,388 E 33,790 N	Alu	Shr sh. H.W. ore fiss. No moisture	150 ft	.00	1.40	.00	.0	.0	.39
				Fe^{III} .3; Al_2O_3 29.56; SiO_2 14.8; Fe^{II}, Ca, Mg,						.00
22–12	22,925 E 33,270 N	Mel+Ep	Fract sh, sltly silic. No moisture	200 ft	.00	.00	.00	.0	.0	26.30
23–12	22,585 E 33,145 N	Ep	Unfract sh. No moisture	350 ft	.00	.25	.00	.0	.0	25.86
24–9	23,643 E 33,680 N	Copi	Fiss qzt. No moisture	Edge of vein fissure	.02	1.00	3.30	.4	.7	22.37
			Quartzite wall rocks							
25–14	22,775 E 33,078 N	Silica, Clay	Fract qzt next to vein. Moisture	2 In.	.00	.00	2.58	.0	19.9	5.60
26–9	33,643 E 33,680 N	Zn, Cu, Mel	Fiss. qzt. No moisture	2 ft from vein	.00	.15	2.30	.0	4.1	38.00
27–14	22,688 E 33,035 N	Pis, Ep	Fract qzt next to vein. No moisture	2 ft	.00	.30	15.88	.0	3.6	13.77

Silver did not migrate more than a few feet in carbonate rocks, if the specimens collected in the Tintic Standard mine are representative. In shale, on the contrary, silver was a common component of the supergene sulfate minerals, both close to ore and in the specimens farthest removed from it. It was not found more than 50 feet from ore in quartzite, and its absence in the specimen collected 100 feet away possibly reflects contact of the solutions with galena and sphalerite, both excellent precipitants—in its journey from the

TABLE 3.

OCCURRENCE AND PARTIAL ANALYSIS[3] OF SOME EFFLORESCENCES COLLECTED IN THE TINTIC STANDARD MINE, AUGUST 1946.

Spec. no. + level	Coordinates[4]	Mineralogy[5,6]	Environment[6]	Distance[6] from ore	Au %	Ag %	Cu %	Pb %	Zn %	H_2O %
			Carbonate wall rocks							
1–12	23,475 E 33,145 N	Gos	Fract ls, sh, jas. No moisture	In low grade Pb-Zn ore	.00	.30	.00	.0	14.9	21.77
2–9	23,644 E 33,681 N	Copi, Ep	Flt; dol, sh, qzt. No moisture	2 ft fr low grd	.00	.25	1.20	.0	2.6	26.42
3–7	23,635 E 33,874 N	Gos, Gyp	Op dol brec. No moisture	35 ft good ore	.00	.00	.54	.0	15.5	20.54
4–9	23,600 E 32,630 N	Copi, Gyp	Flt, dol, sh, qzt. No moisture	95 ft	.00	.00	.00	.0	1.3	24.74
5–9	23,600 E 32,630 N	Szo	Flt, dol, sh, qzt. No moisture	100 ft	.00	.00	.00	.0	.0	5.61
6–8	23,420 E 33,780 N	Ep	Flt, shr sh, dol, qzt. No moisture	160 ft	.00	.00	.00	.0	.0	37.83
7–8	23,420 E 33,778 N	Mixed sulfates esp. Gyp	Flt, shrd sh, dol, qzt. No moisture	160 ft	.00	.00	.00	.0	.0	29.56
8–8	23,420 E 33,774 N	Ep	Flt, shrd sh, dol, qzt. No moisture	160 ft	.00	.00	.00	.0	.0	31.13
9–8	23,035 E 34,445 N	Gyp	Fltd lmy sh+ls. No moisture	160 ft	.00	.00	.00	.0	.0	3.41
10–8	22,965 E 34,460 N	Ep	Fltd lmy sh. No moisture	250 ft	.00	tr	.00	.0	.0	34.15
11–8	22,965 E 34,460 N	Gyp	Fltd lmy sh. No moisture	250 ft	.00	.00	.00	.0	.0	6.64
			Shaly wall rocks							
12–12	22,540 E 33,260 N	Szo?	Mineralized frac. Frac sh. No moisture	Adjac	.01	1.20	.12	.0	.4	7.55
13–12	22,540 E 33,260 N	Copi	Unfract (silic). No moisture	Adjac	.01	.70	.15	.0	.0	17.34
44–12	23,463 E 33,165 N	Chal	On flt, in jasp. No moisture	40 ft	.00	.00	30.8	.0	1.2	25.76
45–12	23,300 E 32,995 N	Copi+Mel	Flt, jasp+qzt. No moisture	100 ft	.00	.15	.94	.0	.9	21.88
46–12	23,360 E 33,028 N	Ep+Mel	Flt, jasp+qzt. No moisture	100 ft	.00	.10	.00	.0	.8	23.31
47–12	23,360 E 33,028 N	Stal, Mel	Flt, jasp+qzt. No moisture	100 ft	.00	.00	.00	.0	10.1	18.88
48–12	32,940 E 33,270 N	Halo (?)	Fract silicified sh. No moisture	200 ft	.00	.00	.05	.0	.0	19.23

Note: See footnote at end of table for explanation of abbreviations used.

[3] Analysis and assays by Christopher E. Schempp.

[4] Tintic Standard mine mapping system.

[5] See table of minerals (Table 2) for explanation of mineral abbreviations.

[6] Abbreviations used:

adjac	adjacent	fltd	faulted	silic	silicified
brec	breccia	fract	fractured	sh	shale
dol	dolomite	lmy	limy	shy	shaly
esp.	especially	ls	limestone	shr	shear
fiss	fissured	op	open	shrd	sheared
flt	fault			stal	stalactitic
				unfract	unfractured

overlying sulfide ore body to the copper- and zinc-bearing efflorescence sampled 100 feet below.

Copper.—Copper is present in some of the specimens of all the leach minerals collected except gypsum and calcite (Fig. 3, Table 3), but makes up more than 1 percent of only chalcanthite, pisanite, and melanterite; it made up approximately 0.1 percent of two specimens of epsomite, but all other epsomite specimens were copper-free. The ability of copper to travel is greatly circumscribed by carbonate wall rocks, and in a limestone and dolomite environment none was found more than a few feet from ore. Copper is moderately mobile in a shale environment, and chalcanthite and pisanite were collected 25 to 40 feet from the nearest source for copper in shale. At greater distances, however, none of the leach minerals contained appreciable copper; copper-bearing solutions traveling long distances in shale would probably have the copper removed by adsorption, a process whose effectiveness was demonstrated experimentally by Sullivan (8) nearly 50 years ago. Quartzite being neither reactive nor adsorptive makes the ideal wall rock for far-traveling copper solutions. Substantial amounts of copper were found in pisanite in quartzite walls as much as 100 feet from the nearest ore body, and nearly every sample of leach mineral collected in a quartzite environment contained an appreciable amount of copper. The only exception was the secondary calcite deposited with the leach minerals, and it contained none.

Lead.—Lead is the least mobile of the five metals studied, but under some conditions it moves a short distance. The few samples of leach minerals containing lead were almost in contact with lead ores and, indeed, specimens 39-9 and 40-9 may have been contaminated by oxidized ore enmeshed in the black, gypsiferous efflorescence. The copiapite of specimen 24-9 (table 3), which contained 0.4 percent Pb, was taken from the walls of a vein in quartzite and probably was not contaminated by either primary or oxidized lead minerals. Its absence from leach minerals not adjacent to lead ore is in harmony with the relative insolubility of its salts; its rare movement may reflect its slight solubility in concentrated sulfuric acid or may be due to the migration of colloidal material released during the solution of host minerals.

Zinc.—As shown in Table 3 and Figure 4, zinc was present in every sample of melanterite and made up from 0.7 to 10 percent of this iron sulfate mineral. It is also present in samples of pisanite and chalcanthite in amounts comparable to the zinc content of the melanterite. The highest zinc content was of course in the goslarites. Some of the epsomite, which is isomorphous with goslarite, carried as much as 5.3 percent zinc at a distance of 150 feet from ore. Specimens of epsomite collected at greater distances contained no zinc. Copiapite and coquimbite may carry as much as 2 percent of zinc, but the metal was not present in all samples.

Zinc travels farther in carbonate rocks than any of the other metals, but no zinc was found in leach minerals in dolomite more than 100 feet from the nearest ore body. Some zinc was found as much as 150 feet from the nearest ore in shale, but was lacking in a silver-bearing specimen of epsomite taken 350 feet from known ore. Zinc was present in the most distant efflorescences collected from quartzite walls.

CONCLUSIONS.

Of the five ore metals studied—gold, silver, copper, lead, and zinc—lead is quite apparently the least mobile and zinc the most dependable traveler. In carbonate rocks, zinc was the only metal found more than 50 feet away from ore, but it too was absent at distances of 100 feet or more.

In pyritic shales all the metals save lead are mobile in the oxidized zone, but gold moves only under oxidizing conditions in strongly acid solutions. Both silver and zinc travel readily in a pyritic shale environment, and silver may persist farther than zinc. The distances that these metals can travel in the shale environment may amount to several hundred feet. Copper does not travel nearly as far as zinc or silver and may be fixed by adsorption during its journey through the argillaceous rocks. Copper, silver, and zinc are all relatively mobile in a quartzite environment, and presumably they would be equally mobile in any other unreactive rock.

It is evident that supergene solutions are less likely to move lead and gold than any of the three other metals studied. They would thus be best suited to indicate the primary dispersion pattern of metals in weathered rocks if contaminating residual soils are eliminated. In rocks containing either carbonate or clay minerals, copper would be a better index of primary dispersion minerals than zinc. In quartzites and similarly unreactive rocks, copper and zinc would be equally undependable as indicators of primary dispersion patterns.

Silver was practically absent from efflorescences collected more than 2 feet from ore in carbonate rocks and may be a fairly reliable indicator of primary dispersion patterns in limestones and dolomites. In shales and quartzites, however, it is so migratory as to be useless as an indicator of primary dispersion patterns such as were sought in the geochemical studies described in the next section.

With due consideration for the many variables that affect the migration of the metals it may be possible to determine proximity to ore bodies by the analysis of efflorescences in mine openings. The most suitable minerals are copiapite, the epsomite-goslarite series, chalcanthite, and the melanterite-pisanite series.

PART II.

PRIMARY DISPERSION PATTERNS OF HEAVY METALS IN CARBONATE AND QUARTZ MONZONITE WALL ROCKS.

H. T. MORRIS.

INTRODUCTION.

As part of the long-range program of geochemical investigataions carried on by the U. S. Geological Survey in the Tintic and East Tintic districts, Utah, since 1947 (10, 15, 16), a study was made of the primary dispersion patterns of ore-stage heavy metals in quartz monzonite and dolomite wall rocks of oxidized and unoxidized ore bodies. The study was undertaken to

determine the distance copper, lead, and zinc penetrated the walls of ore shoots, and the concentration patterns of the metals. This work was originally planned to investigate and develop methods of geochemical prospecting, but the results of the work also suggested some ideas that were new to the writers concerning the solutions that deposited the ore bodies.

Samples were collected outward from contacts of ore bodies with wall rock into barren, unaltered country rock normal to the elongate ore bodies. Wherever possible the sample units were taken along one bed or from a single lithologic unit. Every effort was made to collect uncontaminated material, but it was recognized that the dispersion patterns might be modified by supergene leaching, or by the supergene introduction of secondary minerals. Below the water table, however, the dispersion patterns in the wall rocks of unoxidized sulfide ore bodies probably represent the primary dispersion of heavy metals, unmodified by secondary leaching or enrichment.

In part, the dispersion patterns of the ore-stage heavy metals are remarkably similar to calculated theoretical diffusion curves for the same metals, and suggest a comparatively short-lived source.

Although the distance that the metals migrated into unfractured wall rocks is disappointingly small, several applications of these geochemical studies to prospecting and exploration are suggested.

ANALYTICAL PROCEDURE.

Only a brief outline of the analytical procedures followed in this investigation is presented. The more recent geologic and applied chemistry journals contain detailed articles concerning the analytical chemistry of traces of the heavy metals (see bibliography), and the reader is directed to these sources for a more complete description.

Sampling.—The samples of the wall rock consisted only of the clean core of large fragments collected at distances carefully measured from the edge of stopes or of ore in place. Each sample was pulverized in an iron mortar until all of it passed through an 80-mesh silk screen. Extreme care was taken at all times to prevent contaminating the sample by extraneous material or unclean equipment.

Field Test.—Both laboratory and field methods of analysis were used in this study following procedures outlined by Sandell, Holmes, Almond and Morris, and others (10, 14, 19). For the field test 1 to 5 grams of the pulverized rock was digested 1 hour in an excess of boiling 1 *N* hydrochloric acid in Pyrex test tubes. The solutions were allowed to cool and aliquots were taken directly from the supernatant liquid.

The heavy metals extracted by the acid were reacted with dithizone, and the amount present was estimated colorimetrically by visual comparison of the colored dithizonates with standard solutions. Complexing reagents were used to prevent the interference of other reacting metals. The amount of extracted heavy metals was recalculated to parts per million present in the rock.

Laboratory Procedure.—The altered quartz monzonite wall rock of the Swansea vein and other selected check samples were analyzed under carefully

controlled laboratory conditions for the total amount of heavy metals present. The laboratory procedure is summarized as follows:

The finely ground composite sample is digested in a mixture of equal parts of hydrofluoric and perchloric acids, heated and evaporated to dryness. The heavy metals in the residue are then taken into solution with hydrochloric acid and the heavy metals are estimated as colored dithizonates in the presence of complexing reagents. Zinc is removed before lead is estimated. The opacity of the specific dithizonate monocolor or the mixed color of the dithizonate and the unreacted dithizone solution is determined by a photometer and compared with standards.

Blanks are run concurrently with the samples to check possible contamination by impure reagents and equipment.

The laboratory methods show that the extraction of the heavy metals from the altered igneous rock by the field method varied with the amount of ore-stage heavy metals present but averaged approximately 40 percent of the total. Hydrofluoric-perchloric digestions were not made of the dolomite samples because of the essentially complete digestion of the dolomite by the boiling 1 *N* hydrochloric acid.

PREVIOUS STUDIES.

Previous studies of the heavy metal content of the wall rocks of ore bodies have been made by several investigators, especially between the years 1880 and 1900; these studies were in part responsible for the evidence used by proponents of the lateral secretion theory of deposition of ore bodies. In one of the earliest studies, Sandberger (20) discovered traces of heavy metals in the wall rocks of ore shoots in several mining districts of central Europe; this led him to propose his famous hypothesis of lateral secretion. Pošepnỳ (17), however, marshalled evidence that refuted Sanderberger's theories, and as early as 1893 he stated, "the minute metallic admixtures detected in the country-rock by Sandberger's method are really derived from the ore deposit, i.e., are not idiogenous but xenogenous." Pošepnỳ, however, apparently did little if any original investigatory work on the distribution of metals in country rock near ore bodies.

In the United States, J. S. Curtis (11) during his investigations in the Eureka mining district, Nevada, discovered assayable amounts of introduced silver in the shattered and altered limestone wall rocks of replacement ore bodies for a distance of 75 to 80 feet normal to high-grade silver shoots. The silver content apparently falls with a comparatively flat curve from approximately 15 ppm in the walls of the ore bodies to 8 ppm 30 feet from the vein and to a background of approximately 5 ppm in unaltered limestone 100 feet from ore.

A study nearly identical with the investigations described in this paper was made by Finlayson (12) at the Vieille Montagne Co.'s mine at Nenthead, England, in 1910. The walls of a cross-cut normal to a lead-zinc-silver vein were sampled at regular intervals along a single rock unit—the Great Lime-

stone. The results of Finlayson's analyses, which are presented in Figure 5, are strikingly similar to the results obtained during the present study.

The analytical results of these early studies were obtained by conventional analytical techniques on large samples. It is only with the development of the modern rapid techniques of trace analysis that such studies can be made in sufficient numbers to allow the development of prospecting methods embodying the use of equipment that can be carried in the field, thus obviating the necessity of sending large numbers of samples to centrally located laboratories.

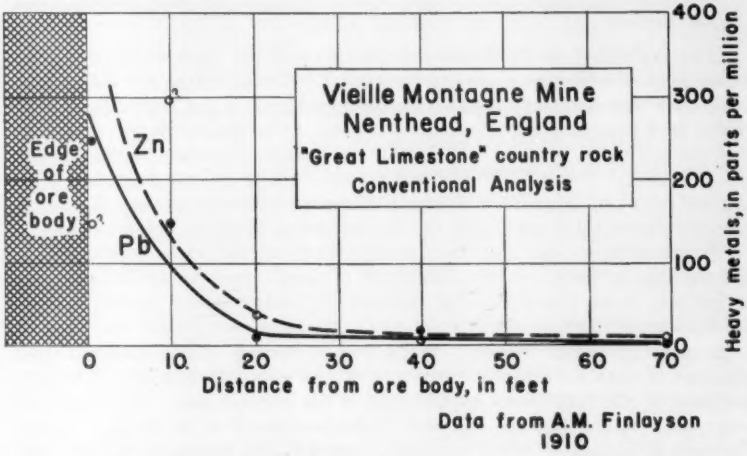


FIG. 5. Heavy metal dispersion pattern, Vieille Montagne mine, Nenthead, England.

EMPLACEMENT OF HEAVY METAL TRACES IN ORE SHOOT WALL ROCKS.

The emplacement of heavy metal traces into the wall rocks of the ore shoots was accomplished by either or most probably by both of two processes:

(a) Circulation of ore-depositing solution through the open spaces of the rock

(b) Diffusion of metal ions through the solutions that filled the available pore space of the fractured and unfractured rock. Consideration of both processes has led to the conclusion that diffusion was probably the dominant operating mechanism, at least during the interval of vein formation and in the areas farthest from the vein.

The circulation of ore solutions in the wall rocks resulted from the existence of a pressure gradient between the zone where the ore solutions were moving, and the unsaturated wall rocks. The initial pressure gradient was doubtless comparatively high but this gradient, in possibly a very short time, was considerably reduced or eliminated when all or nearly all of the

connected pore space in the wall rocks was filled by the earliest solutions. At this time also the smallest connected fractures and pores of the rock were likely filled by the solutions moving outward by capillary action. With the elimination of a pressure gradient and the filling of the open voids, circulation probably ceased in the wall rocks and was maintained only in the ore zone, which presumably is an open system. The heavy metals deposited from these solutions would therefore show irregular concentrations principally close to the ore shoots and related to the local fracture zones, and only under the most ideal conditions of brecciation would show the well-developed, uniform patterns that were determined to occur in many areas some distance away from ore.

The uniformity of the dispersion patterns and the close similarity of the heavy metal distribution curves to theoretical diffusion curves are both highly suggestive that the heavy metal trace concentrations in the relatively unbrecciated wall rocks are the result of diffusion. It is impossible to escape the fact that diffusion continued to operate as long as a concentration gradient existed between the ore solutions that moved through the ore-depositing zone and the relatively stagnant solutions that saturated the wall rocks. This concentration gradient existed until the ore-depositing solution ceased to flow.

Solute diffusion has long been recognized as an important mechanism in the transfer of metals in the formation of some types of replacement ore bodies and in the transfer of the elements that accomplished extensive dolomitization, pyritization, silicification, and other types of diffusive alteration in areas of hydrothermal activity. Metal ions in solution diffuse outward from the zone of high concentration to areas of low concentration at a rate proportional to the coefficients of diffusion of the various ions. The depth of penetration of the ions into the wall rocks is a function of many variables, the most important of which are time, concentration, temperature, and rock properties such as effective porosity in the direction of diffusion, reactivity of the rock, and the size of the pore openings.

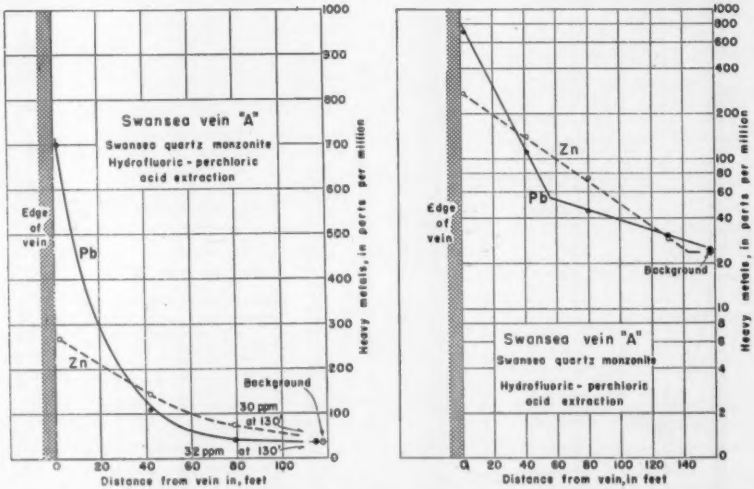
The relative positions of the heavy metal diffusion fronts in the dolomite wall rocks studied appear to result chiefly from concentration and porosity factors, but the reactivity of the wall rocks is of major importance also. This is discussed at greater length below in the descriptions of the heavy metal dispersion curves adjacent to some of the ore bodies studied.

The coefficients of diffusion of zinc and copper in pure water are nearly identical at 25° C, and the coefficient of lead is but slightly greater: ½ Zn^{++} 0.63, ½ Cu^{++} 0.64, and ½ Pb^{++} 0.81 (12). The rate of diffusion of copper and zinc under identical circumstances is, therefore, nearly equal at room temperature; and only differences in relative concentration of the two ions or differences in the chemical reactivity of the two metals under a given set of conditions could cause the diffusion fronts to be noticeably displaced. In an ideal situation, under conditions of equal concentration, lead should be displaced slightly farther outward than zinc and copper. The effect of very small, tortuous pore openings doubtless would act to slow the ions down by collision with the pore walls in the migration of the ions through the rock. Thus the distance of penetration in saturated rocks is somewhat restricted

as compared with diffusion of ions in pure water. It is also possible that the diffusion coefficients of the metals do not change equivalently with rising temperature.

BED ROCK DISPERSION PATTERNS IN TINTIC DISTRICT, UTAH.

Dispersion in Igneous Rocks in Swansea Mine.—Three series of samples were collected from surface exposures of the wall rock of the Swansea vein, which cuts the Swansea quartz monzonite in the southern part of the main Tintic district. This vein is a system of linked and branching fissures that in general trend N 10° W and dip to the west at 87°. The surface stopes,



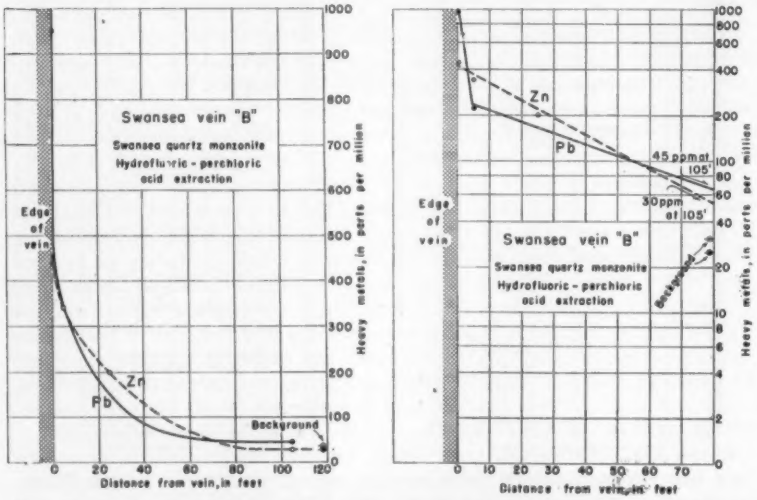
FIGS. 6, 7. Heavy metal dispersion pattern, conventional and semi-log coordinates, sample site "A," Swansea mine, Tintic district, Utah.

mined to a depth of 250 feet, had an average width of less than 6 feet. The ore was richly argentiferous cerusite, with some limonite, anglesite, and residual galena and pyrite all in sugary quartz gangue. The vein walls are silicified, argillized, and pyritized asymmetrically outward from the ore shoot. The vein selvage, which is a foot or two thick, is fine-grained quartz, with sericite and pyrite.

The samples of series "A" (Figs. 6, 7) were collected from surface rocks along a line normal to the vein, in a direction easterly from it. This line extends downhill from the vein apex. Series "B" and "C" of the Swansea quartz monzonite were also collected from outcrop material, along two lines normal to the vein, but westerly from it, approximately 10 and 100 feet north of the "A" sample line. The "B" and "C" lines (Figs. 8, 9, 10, 11, 12)

extend *uphill* into comparatively unaltered Swansea quartz monzonite. The topography is such that downward-moving ground water might cause some contamination of the rock along the "A" line but should not appreciably affect the rock on the "B" and "C" lines.

The average background of primary heavy metals in fresh Swansea quartz monzonite is: Cu 5 ppm, Pb 25 ppm, and Zn 32 ppm. These values compare favorably also with values given for similar igneous rocks by Hevesy and Hobbie (13), and Sandell and Goldich (18). The heavy metal content of the altered rock close to the vein is much higher than the background value, but locally the zinc content of the strongly altered rock adjacent to barren parts of the vein is erratically lower than the background value of zinc in the fresh, unaltered quartz monzonite.



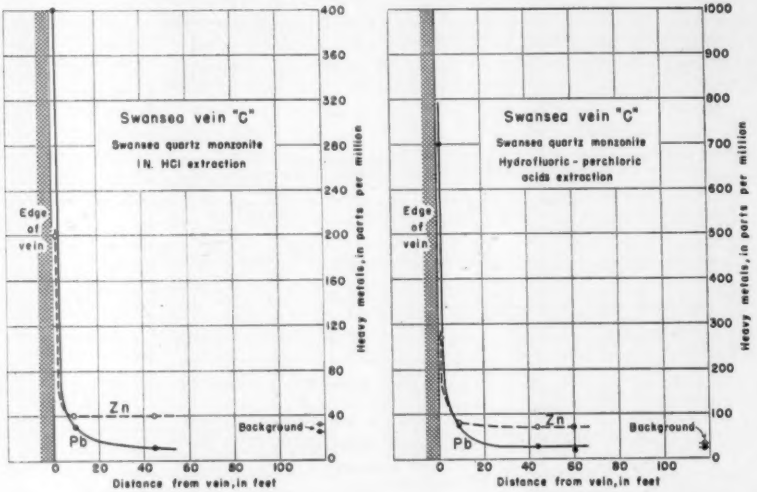
FIGS. 8, 9. Heavy metal dispersion pattern, conventional and semi-log coordinates, sample site "B," Swansea mine.

The vein-wall alteration was accomplished before the ore stage, in part by acid solutions that severely leached the rock close to the vein, and in part by later solutions that formed pyrite at the expense of magnetite in the less strongly altered rock beyond the argillized selvage. The acid, argillizing solutions in leaching the rock created an effective porosity that favored the penetration of solutions into the walls of the fissure that later channelized the through-going ore-depositing solutions. The alteration is recognizable 50 to 75 feet from the vein on the east side, but it is restricted to 5 to 10 feet from the vein on the west side.

The weathering of the pyrite of the pre-ore pyritic alteration gives rise to sulfuric acid, which in zones of strong pyritization may convert part of the

ore stage zinc and copper to sulfates soluble in surface and ground waters. These soluble salts may then be erratically redistributed by surface water. For this reason the dispersion curves of copper and zinc near the surface are commonly irregular, whereas the curves for lead indicate little if any supergene effects. The trace concentrations of lead may, however, be modified by contamination through particles being carried by water moving over the surface of the rocks, or by the wind.

The distance to which the heavy metal anomaly is recognizable ranges from 10 to 30 or 40 feet on the west side of the Swansea vein ("B" and "C" group), but the metals have been introduced several times this distance into



FIGS. 10, 11. Heavy metal dispersion pattern, conventional coordinates, sample site "C," Swansea mine.

the east wall ("A" group). This observation fits well with the field evidence of porous, and more intensely altered rock close to the vein on the east side.

Zinc is displaced outward only slightly farther than lead in the three groups of samples, but lead has been introduced into the immediate walls of the vein in an amount nearly double that of zinc. Such a relation might suggest that solutions with nearly equal concentrations of zinc and lead moved through the vein channel for a considerable length of time and were followed (or preceded) by lead-rich solutions that occupied the channel for a short period of time. During a period of zinc plus lead deposition the diffusion fronts of the two metals would be nearly coincident, but later or earlier lead-rich solutions could conceivably introduce lead in comparatively large amounts close to the channel wall.

Dispersion Patterns in Dolomites.—Samples were collected in the dolomite wall rocks of several replacement ore bodies that crop out at the surface; as a check against the possibility that the surface rocks were contaminated by supergene solutions, a study was also made of the dispersion patterns of the heavy metals in dolomite enclosing totally unoxidized lead-zinc-silver ore bodies 700 feet below the water table. The results obtained from the underground and surface sample suites are remarkably similar.

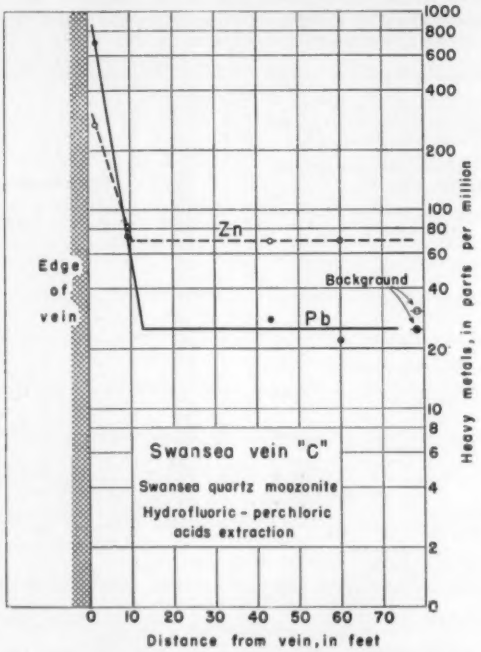


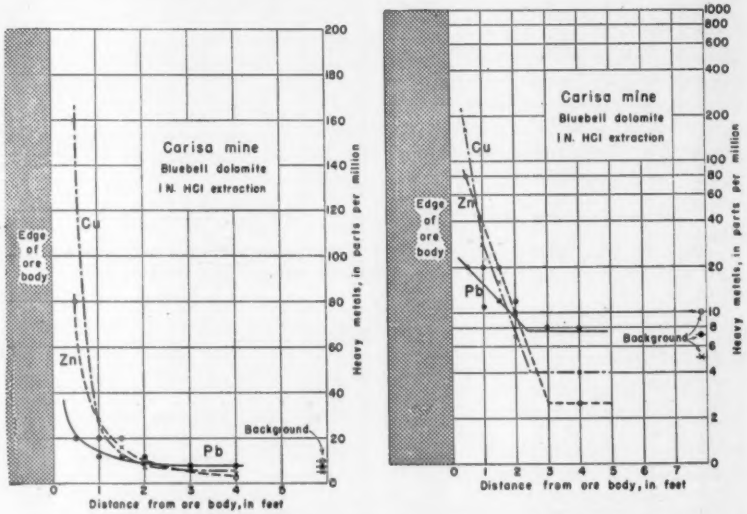
FIG. 12. Heavy metal dispersion pattern, semi-log coordinates, sample site "C," Swansea mine.

Dispersion Patterns Above the Water Table Near Oxidized Ore Bodies in Dolomite.—Dispersion patterns above the water table near oxidized ore bodies in dolomite are represented by the Carisa and Eureka Hill mines. The Carisa copper-gold ore body, now mined out, cropped out at the surface; it had a relatively thin casing of barren jasperoid and was enclosed in marmorized and weakly silicified dolomite. The ore was siliceous and consisted chiefly of copper carbonates and complex copper arsenides assaying from 5 to 40 percent copper, with appreciable quantities of gold and silver and minor

amounts of lead. The unoxidized ore was argentiferous enargite and galena in a gangue of sugary quartz and barite. Zinc minerals were not reported.

The samples for trace analysis included the jasperoid casing of the main ore shoot and the unaltered dolomite. The analytical results are shown in Figures 13 and 14.

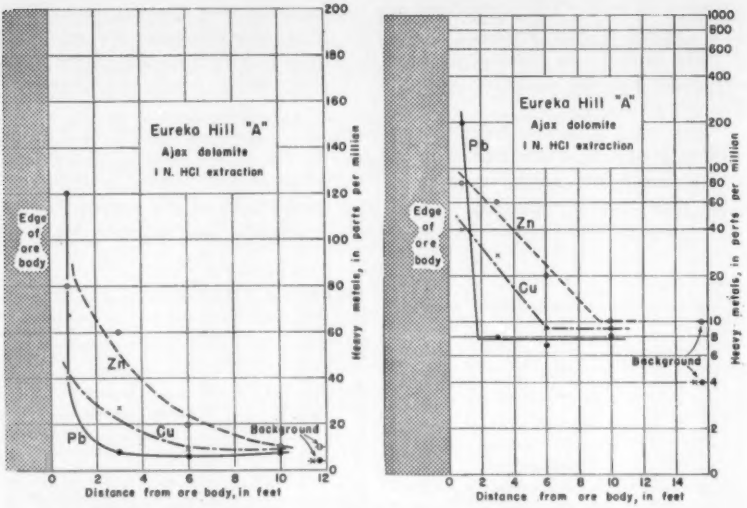
The most apparent difference between the dispersion curves in igneous rock and the dispersion curves in dolomite is the very restricted distance to which the heavy metals move into the walls of ore bodies in dolomite. This difference is especially evident in a comparison of the curves for the ore-shoots in the Carisa and the Swansea mines. The diffusion front of



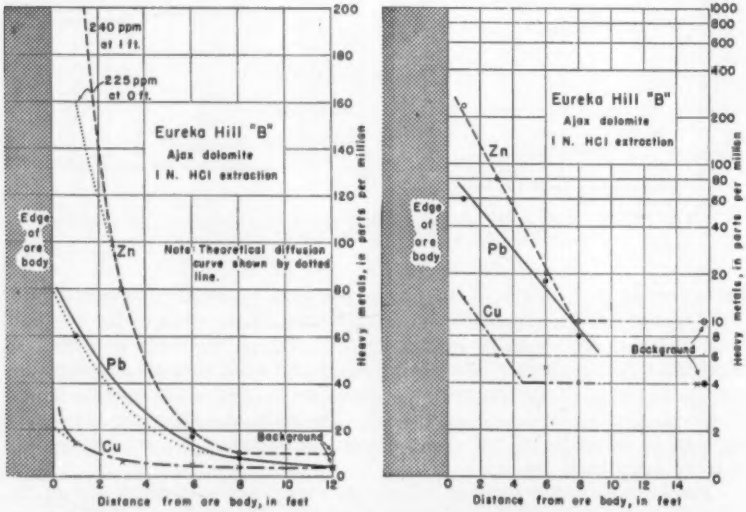
FIGS. 13, 14. Heavy metal dispersion pattern, conventional and semi-log coordinates, Carisa mine, Tintic district, Utah.

heavy metals in the walls of the Carisa ore body is displaced outward from ore 2 feet or less as compared with 10 to 80 feet in the walls of the Swansea vein. This is the result of several factors, perhaps the most important of which are: (a) the highly neutralizing effect and reactive nature of the dolomite, and (b) the greater porosity of the wall rocks of the Swansea vein caused by the pre-ore fracturing and alteration. The walls of most of the ore bodies enclosed in dolomite are not visibly broken or shattered for any appreciable distance away from ore.

The average background of indigenous heavy metals is much less in the dolomite than in the quartz monzonite: Cu 5 ppm, Zn 10 ppm, and Pb 6 ppm. This allows the recognition of much smaller amounts of ore stage metals in



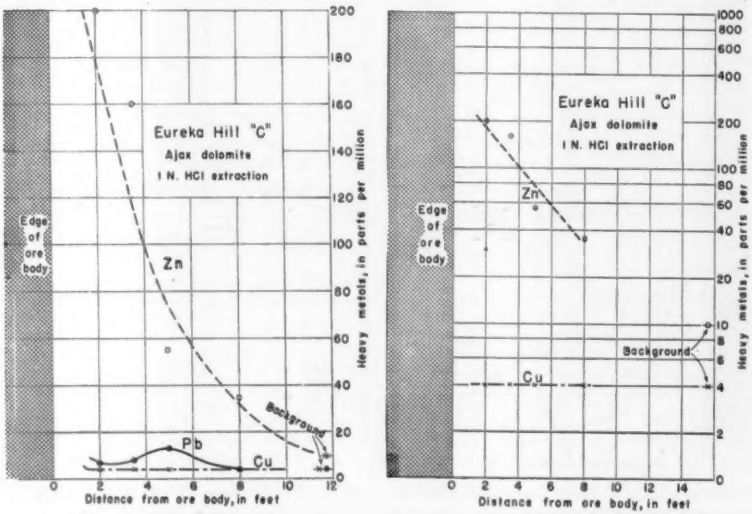
FIGS. 15, 16. Heavy metal dispersion pattern, conventional and semi-log coordinates, sample site "A," Eureka Hill mine, Tintic district, Utah.



FIGS. 17, 18. Heavy metal dispersion pattern, conventional and semi-log coordinates, sample site "B," Eureka Hill mine.

dolomite than in monzonite, but unavoidable sampling and analytical errors discredit the reliability of heavy metal determinataions of any sample within the range of a few parts per million and make results near the range of the background doubtful.

The dispersion pattern of heavy metals in the walls of the Carisa ore body directly reflect the composition of the ore body and probably the concentration of the three metal ions in the ore-depositing solution. The dispersion fronts of copper and zinc are steep, indicating a high concentration for a short duration of time for these metals. The very steep parts of the curves within 6 inches of ore coincides with the jasperoid envelope, and may reflect diffusion of metal ions in colloidal silica rather than in fluid-saturated wall rocks.



FIGS. 19, 20. Heavy metal dispersion pattern, conventional and semi-log coordinates, sample site "C," Eureka Hill mine.

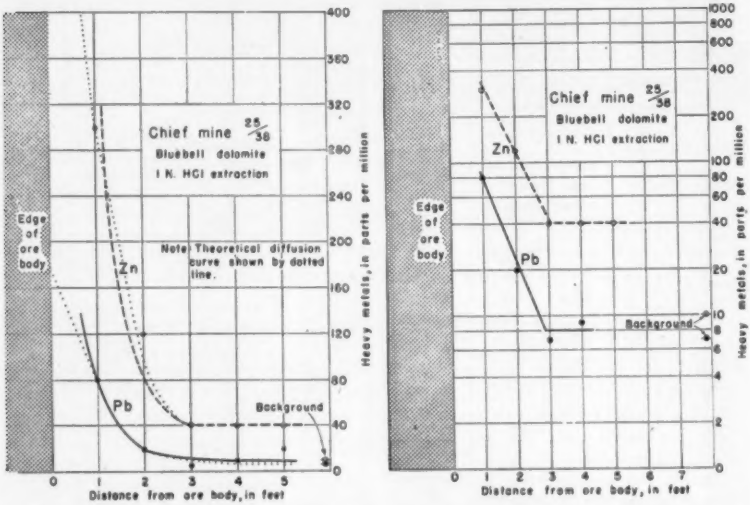
Dispersion curves similar to those obtained for copper and zinc adjacent to the Carisa stope were obtained for zinc and lead in the walls of three "mixed ore" (copper and lead) surface stopes of the Eureka Hill mine. These curves are shown in Figures 15, 16, 17, 18, 19, and 20.

The ore bodies of the Eureka Hill mine crop out in a line extending 1,400 feet south of the Eureka Hill shaft. The stopes that open to the surface have maximum widths of 15 to 50 feet and are in cherty dolomite; the strata are vertical or steeply overturned and dip westward at 75° to 89°. The ore bodies are controlled by the bedding and by bedding-plane faults; they extend to the 200-foot level of the mine in the area investigated.

The ore is fully oxidized, and for years was a source of beautiful specimens of supergene lead and copper minerals. The primary ore minerals are galena, sphalerite, and enargite, silver-bearing in part. Supergene zinc minerals are to be suspected but were not noted in the oxidized ore that remains. The lead and copper minerals occur in a gangue of honeycombed jasperoid.

The dolomite enclosing the ore bodies is almost unaltered, but hypogene replacement of syngenetic chert by coarse-grained calcite and dolomite aggregates near the ore shoots is common.

The nearly vertical wall rock was sampled normal to the steep bedding-plane ore bodies and included several separate beds of dolomite.



FIGS. 21, 22. Heavy metal dispersion pattern in wall rock of 25/38 ore body, conventional and semi-log coordinates, Chief mine, Tintic district, Utah.

The curves differ somewhat from each other, but all those for zinc are similar and all show that dispersion is limited to a zone 8 to 10 feet from the vein. This is several times the distance that the dispersion front is distinguishable in the walls of the Carisa ore body, but it is much less than in the Swansea vein.

In general, displacement of the dispersion fronts outward from the veins harmonizes with the composition and tenor of the associated ore bodies. The Eureka Hill "A" and "B" groups were collected in the walls of oxidized "mixed" copper-lead-silver ore bodies; the Eureka Hill "C" group was collected outward from a lead-silver ore body in the same area but one that was apparently of lower grade, to judge from the pillars of barren, vuggy jasperoid that were not extracted.

Dispersion Patterns Below the Water Table Near Unoxidized Ore Bodies

in Dolomite.—Wall rocks of unoxidized ore bodies 700 feet below the normal water table in the Chief mine were analyzed for heavy metal content. The ore bodies differ only in size from the others described, and are typical replacement ore bodies of the type common in the Tintic district. The ore bodies studied are localized in the Beck fault zone, a major fault having a displacement of approximately 1,500 feet. The ore replaces dolomite and consists essentially of argentiferous galena, sphalerite, and pyrite in a gangue of fine-grained jasperoid and sugary quartz with minor amounts of barite.

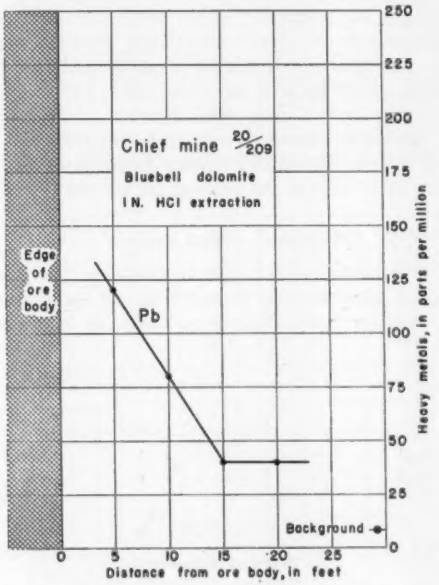


FIG. 23. Dispersion pattern of lead in wall rock of 20/209 ore body, conventional coordinates, Chief mine.

The contacts of the wall rock and ore are well defined, but locally the jasperoid and ore minerals finger out into the wall rocks along irregular channelways.

The samples analyzed for heavy metals were taken from breccia casings of the ore bodies and from the microfractured and recrystallized dolomite that encloses the ore. The dispersion patterns of copper, lead, and zinc in the dolomite wall rocks of these ore bodies are shown in Figures 21, 22, and 23.

The heavy metal dispersion patterns in the wall rocks of the Chief 25/38 ore body, shown in Figures 21 and 22, reflect apparently normal dispersion of lead and zinc adjacent to a small ore body. The lead and zinc dispersion patterns appear to be unmodified by supergene leaching or addition, but the local background for zinc, 40 ppm, is unusually high as compared with the wall rocks of the Eureka Hill and Carisa ore bodies. The principal mineral-

ized part of the Chief mine lies between major ore-controlling faults, however, and the abnormally high background may be the result of widespread dispersion of zinc that is related to the general mineralizing period, or it may have been introduced by ground water when the mine was allowed to flood in 1927. An appreciable amount of zinciferous silt accumulated in the drifts while the levels were under water, in the interval 1927 to 1942. The dispersion pattern of zinc introduced during the deposition of the 25/38 ore body was thus modified by zinc introduced by widespread diffusion during the ore depositing stage or by supergene zinc introduced by ground water. Lead is restricted, however, to the proximity of the ore bodies and their feeding fissures and the wall rocks do not show anomalously high amounts of lead.

The dispersion pattern shown in Figure 23 is for lead in the wall rocks of a small ore body on the 2000 level of the Chief mine, 175 feet below the water table. The zinc curve is not illustrated because of highly erratic results obtained for zinc, probably caused by supergene migration of the zinc in the downward-moving vadose water that passes through a very large body of oxidized ore on the 1800 level of the mine above the 2000-level ore body.

ECONOMIC APPLICATIONS.

Heavy metal trace studies of the type described in this paper, but slightly modified, have several applications in prospecting and exploration. One of the more promising of these applications, especially in limestone replacement

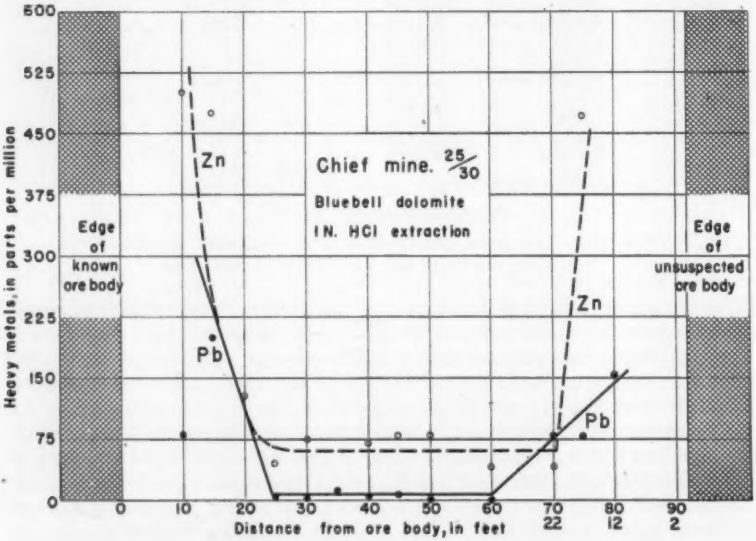


FIG. 24. Heavy metal dispersion pattern, 25/30 sample area, 2500 level, Chief mine.

TABLE 4.

HEAVY METAL CONTENT OF WALLS AND BRECCIA FILLINGS OF FRACTURES IN AREAS OF METALLIZATION IN CHIEF NO. 1 MINE (PARTS PER MILLION).

Hypogene metals, ore feeder fissures.

	Cu	Zn	Pb	
No. 1	16	115	24	Wall rock
(Area of intense	36	540	192	Fissure (breccia filling)
mineralization)	6	173	48	Wall rock
No. 2	12	86	24	Wall rock
(Area of intense	72	713	240	Fissure (breccia filling)
mineralization)	12	173	48	Wall rock
No. 3	2	30	4	Wall rock
(Area of weak	3	135	40	Fissure (breccia filling)
mineralization)	2	30	8	Wall rock

Supergene and hypogene metals, barren (?) fissures.

	Cu	Zn	Pb	
No. 4	24	346	24	Wall rock
(Area of intense	48	713	48	Fissure (breccia filling)
mineralization)	12	346	72	Wall rock
No. 5	8	86	24	Wall rock
(Area of moderate	96	713	24	Fissure (breccia filling)
mineralization)	40	173	24	Wall rock

Metals along barren fractures not known to be related to ore bodies.

	Cu	Zn	Pb	
No. 6	5	18	7	Wall rock
(Supergene	7	84	8	Fissure (breccia filling)
introduction)	5	18	7	Wall rock
No. 7	5	10	7	Wall rock
(Weak supergene	7	40	8	Fissure (breccia filling)
introduction)	5	11	7	Wall rock

districts such as Tintic, is the use of trace analysis to distinguish the commonly unmineralized feeding channels of pod-like ore bodies from barren fractures not related to mineralized ground. Preliminary studies by the U. S. Geological Survey and supplementary investigations by the geologic staff of the Chief Consolidated Co. (Tintic district, Utah) have shown that the walls and breccia fillings of fault and fissure zones known to connect above or below with large replacement ore bodies may average several hundred parts per million of lead and zinc higher than the barren fractures that were not channelways for the ore solutions. Table 4 shows a few selected results of such a study on the lower levels of the Chief mine and the adjoining Eagle and Bluebell mine. Owing to the comparative immobility of lead and the wide supergene migration of zinc, a high concentration of lead is a much more reliable indicator of the passage of hypogene solutions than is a similar con-

centration of zinc. Fissures containing a significant amount of zinc but no introduced lead probably reflect supergene introductions, as has been described in Part I of this paper; this supergene concentration of zinc may, of course, indicate the presence of unfound oxidizing ore bodies. No breccia-filled fractures in the stoped areas of the mines were found to be totally barren of introduced zinc.

Sampling of drift walls at close intervals is another possible approach, especially in districts—such as Tintic—where mine workings may pass within

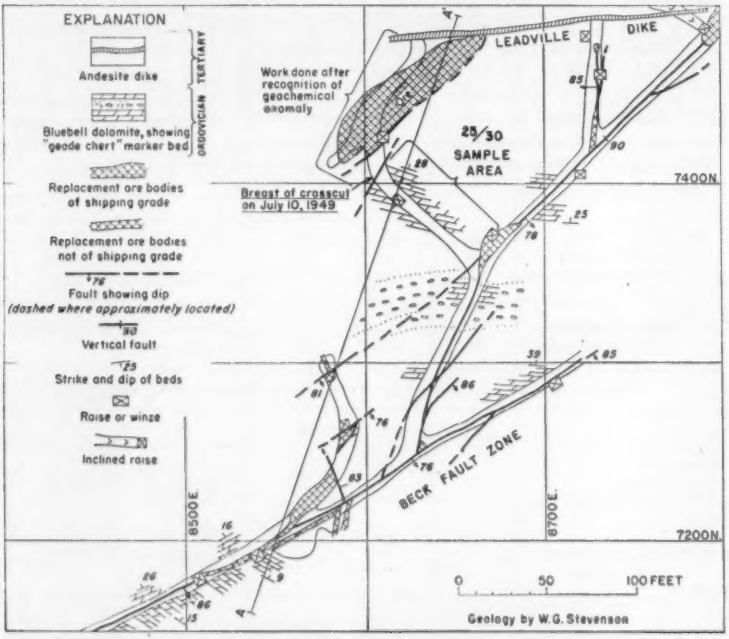


FIG. 25. Part of 2500 level, Chief mine, Tintic district, Utah.

a few feet of an ore body without disclosing mineralized ground. Such a program in large mines would be an ambitious undertaking, unless it was restricted to especially promising areas.

The systematic sampling of a drift in barren rock to establish the diffusion curve in the wall of a small, unminable ore body on the 2500 level of the Chief mine, however, fortuitously resulted in the disclosure of a dispersion pattern related to an unsuspected 12,000 ton ore body nearby. This ore body averaged 7 oz. of silver to the ton, 6 percent lead, and 7 percent zinc. A geologic map of part of the Chief 2500-level showing mine development before and after the disclosure of the ore body and after its extraction is shown in Figure

25. The dispersion curve in the barren wall rock between the known and unsuspected ore bodies is shown in Figure 24. The recognition of the geochemical anomaly was an important contributing factor in the later decision to undertake additional development work, but there were, of course, many other considerations that determined this particular exploration. It is of special interest, however, to note that only 12 feet of barren-appearing limestone separated the ore body and the face of the crosscut when it was stopped in the initial exploration.

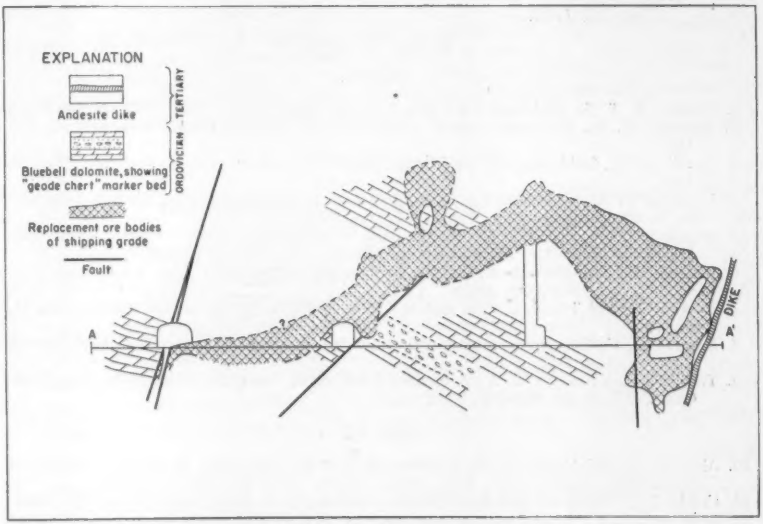


FIG. 26. Projected section through A-A', Figure 25.

Continuing geochemical studies are being made by the geologic staff of Chief Consolidated Co. as an adjunct to conventional exploration and prospecting methods.

GENERAL CONCLUSIONS.

1. Copper, zinc, and lead are dispersed in the wall rocks of base metal ore bodies in patterns that in part strongly suggest diffusion.
2. The dispersion fronts of the metals are restricted to within 10 feet of ore in dolomite, but may be displaced several times this distance in the walls of certain veins cutting igneous rocks.
3. The ratios of the heavy metals present in the wall rocks are related to the composition of the ore bodies with which they are associated.
4. The metal content of the wall rocks decreases logarithmically, and the plotted curves strongly suggest diffusion from a short-lived source, which

probably was undergoing rapid precipitation and a concomitant drop in concentration of the metal ions in the mineralizing solution.

5. The dispersion patterns of lead, and locally of zinc and copper, in the wall rocks of oxidized ore bodies at or near the surface compare favorably with those for metals adjacent to primary sulfide ore bodies 700 feet below the water table.

6. Several economic applications of the general principles established are possible.

U. S. GEOLOGICAL SURVEY,
WASHINGTON 25, D. C.,
June 10, 1952.

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SOME SIMPLE AIDS IN THE HYDROTHERMAL INVESTIGATION OF MINERAL SYSTEMS.

RUSTUM ROY AND E. F. OSBORN.

ABSTRACT.

Modifications of existing pressure equipment for hydrothermal studies are described. These include the use of a jack as a simple means of generating high pressures in standard vessels, the conversion of pressure vessels into rod mills for grinding at elevated temperatures and pressures, and changes in design of pressure vessels.

INTRODUCTION.

DURING the past few years investigations of phase equilibria in mineral systems at elevated temperatures and high water pressures have greatly increased in number and in scope. For example, systematic studies at high water pressures have recently been made on such systems as: $MgO—SiO_2—H_2O$,[1] eucryptite-silica,[2] $Fe_2O_3—H_2O$,[3] $Al_2O_3—H_2O$,[4] $NaAlSi_3O_8—CaAl_2Si_2O_8$,[5] $KAlSi_3O_8—NaAlSi_3O_8—H_2O$,[6] $KAlSi_3O_8—NaAlSi_3O_8—SiO_2$,[7] $MgO—Al_2O_3—H_2O$,[8] $MgO—Al_2O_3—SiO_2—H_2O$,[8,9] and $Al_2O_3—SiO_2—H_2O$.[10] The rapid progress in this field of research is due in large part to the recent development of satisfactory and simple laboratory techniques, the "Tuttle apparatus" [11] being probably the most significant recent development. In our hydrothermal

[1] Bowen, N. L., and Tuttle, O. F., The system MgO-SiO_2-H_2O: Geol. Soc. America Bull., vol. 60, no. 3, pp. 439–460, 1949.

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[11] Tuttle, O. F., New hydrothermal quenching apparatus: Amer. Jour. Sci., vol. 246, no. 10, pp. 628–635, 1948.

studies during the past four years, we have had occasion to simplify or redesign certain types of equipment. A brief description is given below of some ideas which have proved useful.

HIGH PRESSURE DEVICE.

In almost all the work described in the literature in which pressure has not been generated by the simple confinement of the vapor within a closed space, a pump originally designed for gas or oil compression has been used with water actually in the whole system. It was our experience that these pumps,

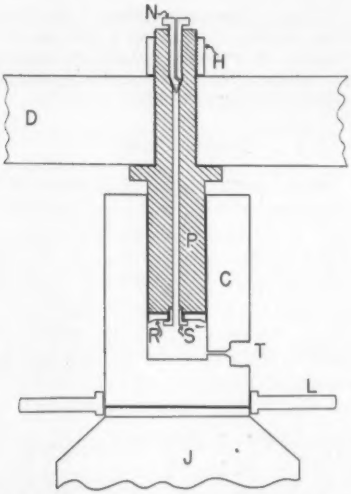

FIG. 1. Diagram of pressure chamber and piston. C = stainless steel chamber, P = stainless steel piston with shoulder and threaded section, T = standard ¼ in. fitting with 60° cone, R = rubber or teflon washer, S = hollow bolt to hold washer against piston and permit escape of air, N = needle valve seated in piston to control flushing out of air, H = ordinary hexagonal nut to hold piston, L = centering ring to hold chamber on jack, with arms to allow leverage when it is necessary to move chamber away from piston, and J = ordinary commercial jack (rated 20 tons).

which are rated for 30,000 psi, require constant attention due to the wearing away of the ball and cone seat and the compression of the packing around the piston. Moreover, such a pump is rarely able, in our experience, to supply 30,000 psi pressure except for the first few days after it has been reconditioned; it also requires many minutes to come up to pressure. A very simple device, illustrated in Figures 1 and 2, was therefore designed and constructed. It consists of a stainless steel chamber and piston in which water is compressed by means of a commercial jack. The seal is effected very simply by a rubber (or preferably Teflon) washer which is squeezed out more and more by the

pressure itself. To operate the pump, water is drawn into the system from the brass reservoir, *W* (using a lever if necessary to force the chamber away from the plunger), by opening valve *A* and lowering the chamber to its lowest position. Valve *A* remaining open, needle valve *N* is opened to let any air out until a drop or two of water flows out, and then shut. Valve *A* is then shut off and by raising the jack upward, the water is compressed to give the desired pressure. It is usual to fill the pressure vessels full of water and bring them up to the temperature desired, and then by opening valve *B*, bring the system up to the desired pressure and again shut valve *B*. In this manner, with a suitable system of valves, it is possible to operate a large number of

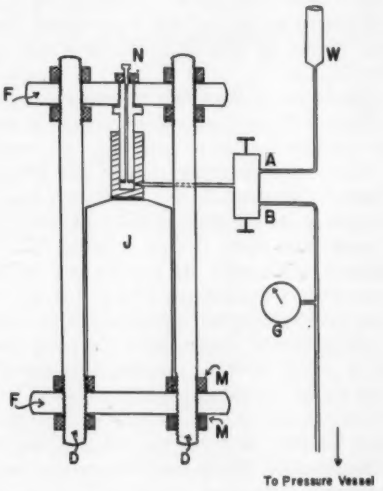

FIG. 2. Pressure system assembly. $F = 1\frac{1}{2}$ in. thick steel or cast iron plates, D = cold rolled steel rods, $1\frac{1}{2}$ in. in diameter, M = standard hexagonal nuts, J = jack, A = upper half of two-stem three way valve, B = lower half of two-stem three way valve, W = covered reservoir for distilled water, G = pressure gauge, and N = needle valve for air escape.

pressure vessels from the same compressor. With this compressor the pressure in a vessel of relatively small capacity (1 ml. or less) can be raised to 50,000 psi within 10 to 15 seconds. So far our experiments have been confined to pressures within the limit of the gauge and the valves, reportedly 60,000 psi. However, even new commercial valves were found to leak at this pressure. If only one pressure vessel is to be used, valves may be eliminated, making possible the use of pressures as great as 100,000 to 200,000 psi. The frame consists of $1\frac{1}{2}$ to 2 in. thick steel plates held together by four $1\frac{1}{2}$ in. diameter cold rolled, threaded steel rods, and nuts. All valves, tubing, sleeves, and nuts in contact with the water were made of stainless steel.

GRINDING AT HIGH TEMPERATURE AND PRESSURE.

During the course of hydrothermal phase equilibrium studies it was our experience that several stable phases, especially anhydrous oxides, would not come to equilibrium with water under the usual static conditions in the pressure vessels used, within any reasonable length of time (i.e., a few months). Since the chamber of a Morey type vessel is a large cylinder, a number of 18–8 stainless steel rods (usually four, 2 each of diameter 3/16th and 1/8th in.) were placed along with the charge and desired volume of water inside the vessel and sealed in the usual manner with a silver washer. The whole vessel was rotated by screwing the plunger into a holder attached to a 20 rpm shaft. Four such vessels are rotated in separate furnaces using a chain drive from the reduction gears. We have found that the 4 ml vessel, described below, containing smaller rods, serves as well or better as a rod mill than the larger bomb.

We have been able to grind materials at temperatures up to 450° C and water pressures as high as 10,000 psi. The material is usually introduced as a $-80+120$ mesh powder and, after grinding, the product fractionated by settling methods. Some results obtained with the apparatus will serve to illustrate its usefulness. The particle size (determined in the electron microscope) of a large portion of the sample is of the order of 0.1 micron after grinding for about two weeks and down to 0.05 micron after two months. Minerals such as andalusite, sillimanite, or kyanite can be decomposed to give kaolinite at the appropriate temperatures within 3 days. The decomposition is sufficient to enable the kaolinite to be detected in the x-ray diffraction patterns, whereas in static pressure vessels under the same conditions of pressure and temperature, in a period of three months, only the slightest trace of reaction can be noticed under the microscope, the amount of kaolinite being far too small to give an x-ray pattern. Similarly, spinel can be decomposed to yield corundum plus brucite, or cordierite decomposed to yield serpentine (other phases not identified). These reactions cannot be made to proceed at all under static conditions.

PRESSURE VESSELS.

A small 4 ml chamber Morey type bomb, constructed of Type 316 [12] stainless steel, has proved to be economical and also more efficient than the larger vessels. In the large vessels the bottom parts were of the 18–8 stainless steel and the tops of a chrome-molybdenum (S.A.E. 4140) steel. We have experienced no seizure with Type 316 stainless steel although both top and bottom were made of the same material. Temperatures can also be read somewhat more accurately. A lubricant consisting of a suspension of ground mica in a solid grease has completely eliminated seizure in all instances, even when Morey type bombs have accidentally been heated to 700° and 920° C.

Workers at the Geophysical Laboratory of the Carnegie Institution of Washington have used as a pressure vessel an 8-in. steel tube closed at one end and connected at the other end to a pressure system. The sample was supported on top of a rod inserted within the tube, the closed end at the top

[12] Obtained from Joseph T. Ryerson and Son, Inc.

being heated to the desired temperature and the closure being made by a cone and cone seal which is outside the furnace. We have used extensively a modification of this set-up where the essentially heavy-walled stainless steel "test-tubes" of inner diameter varying from ¼ to 1/16 in. are heated with the closed end down. The samples are inserted after wrapping in platinum envelopes, and then a loose-fitting stainless steel rod inserted to minimize convection and transfer of material. This type of vessel is very economical and even if made of ordinary 18–8 stainless steel will withstand 750° C at 5,000 psi indefinitely, and 800° C for short intervals. Moreover, they may be quenched more rapidly than possibly any other type of hydrothermal vessel by removing the furnace and simply immersing in water.

ACKNOWLEDGMENT.

We are indebted to Mr. Clemens Schoenebeck and Mr. J. I. Weaver of the Mineral Industries School shop for suggestions in design and the execution of the machine work necessary in the apparatus described.

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THE PENNSYLVANIA STATE COLLEGE,
STATE COLLEGE, PA.,
May 26, 1952.

RADIOACTIVITY AS A GUIDE TO ORE.

W. H. Gross.

ABSTRACT.

One of the principles of prospecting is to confine detailed exploration to relatively small areas considered most favorable for the occurrence of ore. Ore is often found in and around the boundaries of igneous intrusives and a method is given for localizing ore-search around intrusives ranging in size from small stocks to batholiths. The method is based on the occurrence of broad areas of higher-than-normal radioactivity in the igneous rock in the vicinity of ore structures. Nine intrusives were examined and high radioactive anomalies occurred in the neighborhood of associated ore bodies, whereas no such concentration was found in two intrusives barren of ore.

The distinctive association of radioactivity with ore is believed to be independent of whether the so-called igneous body was formed from a cooling magma or from heated and recrystallized sediments; or whether the ore solutions were genetically related to the present erosion surface or were derived from unknown sources at some greater depth.

INTRODUCTION.

The prospecting technique described in this paper gives the results of five years' development work at the University of Toronto. It should be made clear, immediately, that the technique is not presented as a prospecting panacea, but rather as a general aid and guide that should be applied in the field in conjunction with all available geologic data. The method is the outgrowth of earlier work done by Ingham and Keevil (11),[1] Slack (20), and others who have studied the distribution of radioactivity mainly as it concerns the rate of production of radiogenetic heat in four granitic batholiths located in Ontario and Quebec.

Gratitude is expressed to the Research Council of Ontario for a grant of money to purchase equipment and to the Ontario Department of Mines for the zirconium determinations. Appreciation is also extended to a number of students at the University who did much of the work involved in sampling and assaying. These men include P. R. Heenan, C. A. Krause, A. C. Newton, W. A. Nethery, R. W. Stevenson, W. D. Hicks, and R. A. Hill. The specimens from McIntyre Mine were collected by A. D. Mutch and from the Falcon Lake stock by G. D. Springer. Messrs. Stevenson and Hill collected and analyzed the specimens from the Larder Lake and Kamiskotia areas. Dr. W. W. Moorhouse was kind enough to read and check the manuscript.

[1] Numbers in parentheses refer to Bibliography at end of paper.

THEORETICAL CONSIDERATIONS.

It is believed that a study of the distribution of radioactivity in stocks and batholiths can serve as a useful guide to ore. However, before the technique and field results are described, it will be useful to discuss the principal assumptions on which the method is based so that the reader may evaluate it in the light of his own particular geologic prejudices. It is suggested to those who are not interested in the theoretical background of this method that they turn directly to the section headed "sampling."

1. *Late Solutions, Which Include The Pegmatite And Hydrothermal Stages In A Crystallizing Intermediate To Acid Magma, Will Be Relatively High In The Radioactive Elements.*

That this proposition is reasonable is suggested by the following evidence:

a. In a differentiating magma, the more siliceous rocks are generally considered to crystallize later and at a lower temperature than the less siliceous types. Radioactivity of rocks increases with the silica content (5) and, therefore, it may follow that the radioactive minerals in the rock crystallize late.

b. Radioactive minerals are concentrated in pegmatites and, at times, in hydrothermal veins which are believed to be late phases of a crystallizing magma.

c. A large proportion of the radioactive elements in rocks occurs around grain boundaries of the essential rock-forming minerals. This was found to be the case for granites by Hurley (10), Picciotto (17) and others. It seems that the radioactive elements tend to concentrate in the acid-type pegmatites but actually much is trapped around the early-formed crystals of the parent igneous rocks.

By exposing alpha track plates[2] on thin sections without cover glasses, after a method described by Poole and Bremer (18), an approximate distribution of alpha-particle activity in relation to the position of mineral grains was made for a number of rocks.[3] Figure 1 shows some examples, taken at random, of microscopic traverses under high power made across rock sections, which are drawn to scale, and the corresponding positions of alpha activity taken from photographic plates. Where possible, the samples were obtained below the possible reorganizing effects of supergene solutions. Positions of grain boundaries and alpha tracks were plotted only to the nearest 0.1 mm. The crystal grains are mostly several tenths of a millimeter across so that the work is believed to be sufficiently accurate to show that much of the radioactivity occurs around boundaries of early-formed crystals. Such appears to be the case for rocks ranging in composition from diabase to granite-aplite. The intercrystalline location of the alpha tracks helps substantiate the claim that radioactive minerals crystallize late.

[2] Kodak Nuclear Track Plates, Type NTA, Emulsion thickness 50 microns—exposure time 60 days.

[3] Done with the help of C. V. G. Phipps.

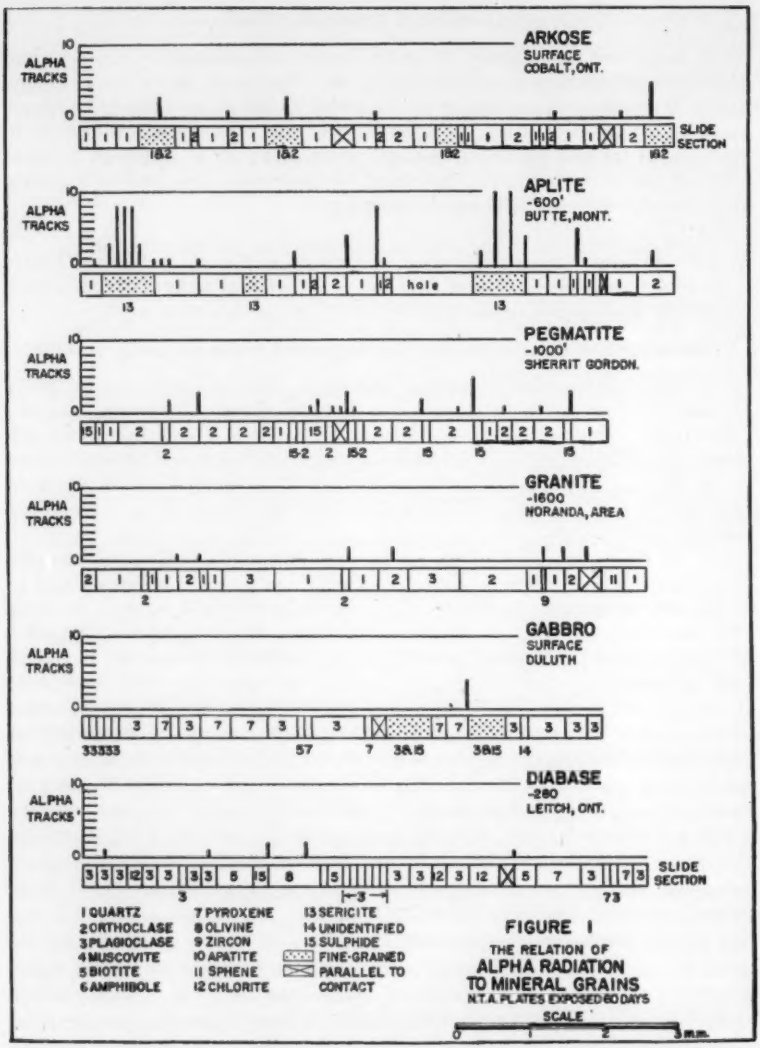


FIGURE 1

THE RELATION OF ALPHA RADIATION TO MINERAL GRAINS

N.T.A. PLATES EXPOSED 60 DAYS

Traverses of the type shown in Figure 1 are roughly quantitative, and it can be seen from the figure that the radioactivity, as exemplified by the alpha activity for equal traverse distances, increases from the basic to the more acid rock types.

An example of the radioactive distribution in an arkose is also shown on Figure 1. As might be expected for a medium-grained sediment, the bulk of the radioactive elements appears to occur in the fine-grained material around the particle grains.

2. *Late Solutions From Crystallizing Magmas Will Tend To Flow To Areas Of Lower Pressure. Normally, These Solutions Will Be Moving Down A Temperature Gradient So That Deposition From The Solution Will Take Place.*

The liquid fraction, which remains at a late stage in the cooling history of a magma, will have a lower specific gravity than the solid fraction. The difference will be great if the solutions contain a high proportion of water and

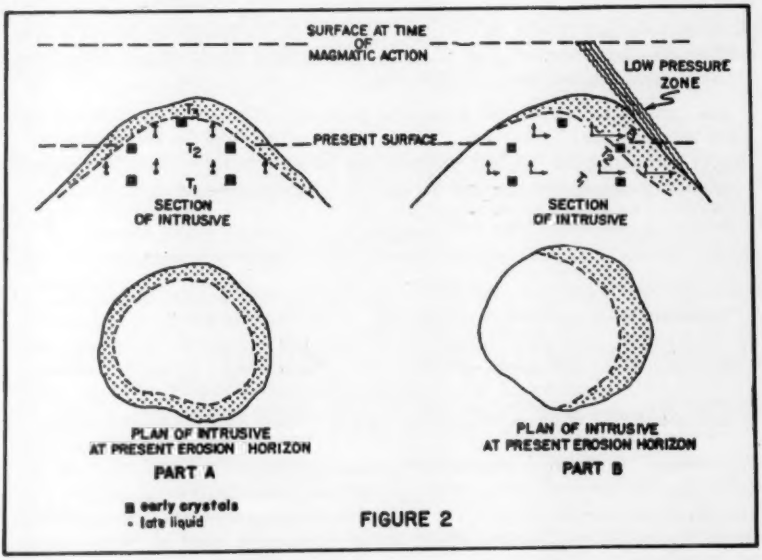


FIGURE 2

other hyperfusibles. Because of the density difference the liquid will try to move vertically upward through the mush of crystals. Should the liquid move upward, it will generally meet with lower temperature conditions and deposition from the solution will take place. If the magma is deeply buried and sealed, the late products will try to concentrate at the top and sides of the intrusive as shown in Part A of Figure 2.

The pressure in a magma at a late stage in cooling is believed to be high (16). If relatively low-pressure areas, such as faults or fractures, occur in the vicinity of the intrusive, then late solutions will tend to flow towards these low-pressure areas. Here again, the solutions move down a temperature

gradient so that deposition from the solution may take place (Part B, Fig. 2). There will, no doubt, be all variations between the two simple and idealized cases presented here.

If the intrusive is exposed by erosion, then some idea of the flow direction of the late solutions in the magma could be obtained by analyzing the surface of the intrusive, as the direction of flow will be towards areas of concentration of the late crystallizing products. If the radioactive minerals crystallize late (assumption 1), then the flow directions in a magma will be towards areas of higher than normal radioactivity.

Because the bulk of the radioactivity is located around the fragment grains, early solutions from recrystallizing sediments will probably be relatively high in radioactivity so that migrations of these solutions to zones of lower temperature and pressure may also be indicated by high radioactive anomalies.

3. *Late Solutions Which Are Relatively High In Radioactivity May Or May Not Be Ore Carriers, But Normally They Will Move Along The Same Structural Channelways As The Ore.*

A current theory of ore formation postulates that ore minerals concentrate into so-called hydrothermal solutions at a late stage in the cooling of a deeply buried magma. These solutions are believed to flow through structural channelways where ore is deposited mainly by decrease in temperature.

TABLE 1.

Area	Intrusive	Ore	Pegmatites
Porcupine, Ont.	Pearl Lake Porphyry 1.4/63*	McIntyre 0.8/5	—
Larder Lake, Ont.	Syenite 2.8/23	Omega 0.7/5	5.2/5
Red Lake, Ont,	Granodiorite 2.6/60	Orlac 1.4/7 Cochenour 0.11/6	3.9/10
Athabaska	Athona Stock 5.1/28	Athona 0.8/5	16.8/10
Kenora Area	Quartz Monzonite 1.7/23	—	6.8/10

* 1.4/63 = 1.4α/cm³/hr. Average for 63 separate, random samples.

Ores are normally much lower and corresponding pegmatites are generally much higher in radioactivity than the igneous rocks cited as their source. Examples of the relative difference in radioactivity of these rock types are shown on Table I.

Although there is lack of unanimity regarding the relation of pegmatite and hydrothermal solutions, the prevailing conception is that the two solutions share events in a late stage in the cooling of the magma. Therefore, movement and concentration of one solution will be reflected, in a general way, by movement and concentration of the other. Should the hydrothermal solutions be drawn into structural channelways where ore is deposited, then their direction of movement will be indicated by the flow direction of the pegmatite solutions, which, in turn, may be manifested by an increase in the radioactivity of the intrusive mass in the direction of flow. A certain disparity is to be ex-

pected between the exact locations of ore and areas of higher-than-normal radioactivity in the intrusive due to the differences in viscosity, and possibly the timing, of the pegmatite and hydrothermal phases.

Unfortunately, there are some complications to this rather simple conception of ore formation. Some ores appear to have a more complex genetic history. For example, gold ores in many districts commonly result from at least two distinct ages of mineralization. White (24) believes, after examining gold ores from 37 districts in North America, that gold is deposited at a late stage in the vein history at a relatively low temperature.

An attempt was made [4] to determine the approximate temperature of formation of the separate periods of mineralization in samples from 108 separate gold-quartz-pyrite veins from various sections of northwestern Ontario and eastern Manitoba. The decrepitation and pyrite geothermometer techniques advanced by Smith (19, 21) were used and the results are shown on Table 2.

TABLE 2.

District	No. of veins sampled	Quartz decrepitation temp. ° C		Pyrite geothermometer ° C	
		Low	High	Low	High
Kenora, Ont.	19	85–175	305–330	140–225	430–500
Red Lake, Ont.	25	75–130	295–400	155–235	440–525
Rice Lake, Man.	11	85–136	285–425	195–230	400–470
Miscellaneous	53	85–174	245–400	160–240	380–605

Skeptics of Smith's work will argue that the temperature values obtained by these methods are subject to errors. Nevertheless, the results substantiate the microscope observations of two periods of mineralization and suggest that one age was formed at relatively high temperature (above 380° C), whereas the other (gold-bearing) was formed at relatively low temperature (140–240° C).

The first high temperature mineralization could have migrated directly from some nearby magma. The question arises, however, as to the genesis of the later, low temperature, gold-bearing period. Recourse, in this case, is generally to some unknown source at greater depth (although usually safely related genetically to the nearest intrusive). If these opinions are valid, then there would be little connection between late migrating solutions from the magma, which presumably we can trace by virtue of the concentration of the high radioactivity of the pegmatite stage, and the later ore-bearing solutions that come from depth.

On the other hand, the two ages of mineralization, in the case of gold ores at least, generally occur together, which strongly suggests that a single structural control influences the course of both ages of mineralization. It is a common observation that many ore-bearing structures (folds, faults, and related fractures) have pre-ore, ore, and post-ore movement. During magmatic activity and orogeny these structures are alive and active.

[4] With the assistance of W. J. Casburn.

Thus it is conceivable that the concentration of radioactivity in an intrusive may indicate the flow of late solutions toward relatively low-pressure structural areas, and thus indirectly indicate structures that are the most likely conduits through which later ore-bearing fluids might pass.

4. *The Primary Distribution Of Radioactivity In Stocks And Batholiths Will Not Be Seriously Affected By Alteration Changes Of Later Hypogene Solutions.*

Earlier it was suggested that a good deal of the radioactivity in rocks is intercrystalline. Should grain boundaries of minerals be replaced in wall rock alteration processes associated with ore formation, then it might be expected, since ores are generally low in radioactivity (Table 1), that alteration zones around ore bodies would be lower in radioactivity than the unaltered rock equivalent.

To determine if the redistribution of radioactivity around ore bodies is so widespread as to affect the interpretation of high radioactivity in its broad relation to ore, six field cases were examined as shown in Figure 3. In the cases chosen, it can be seen that the radioactivity decreases rapidly over a relatively short horizontal distance from the granitic intrusive through the altered intrusive to the ore. Where the country rock was material of basic composition, and hence inherently low in radioactivity, there appears to be only a slight decrease towards the ore which, in fact, may not be real, as it is within the error of measurement of the alpha-counting equipment used.

If the four assumptions made above are valid it can be expected that in such igneous bodies as stocks and batholiths there will be a broad area of higher-than-normal radioactivity in the vicinity of relatively low pressure areas, such as major fault and fracture zones, which occur nearby. The association of radioactivity in igneous rocks to major structures will occur whether the so-called igneous body and the ore is formed from cooling magma or from heated and recrystallized sediments. Finally, the structures that are indicated by areas of higher-than-normal radioactivity may act as channelways for ore solutions or, in fact, as a locus for the ore itself. It follows, then, that zones of higher-than-normal radioactivity in large igneous-like masses will occur in the vicinity of related ore bodies that are controlled by major structural features.

In order to test the foregoing conclusion, the distribution of radioactivity was obtained for nine intrusives. Some were also analyzed for their zirconium, silica, and heavy metal content. Zirconium was determined because of the close association of the mineral zircon with the radioactive elements (17) so that general agreement in the distribution between these two constituents would be expected. Furthermore, although zircon is rare in hydrothermal deposits it is common in pegmatites, which suggests that it is late to crystallize from the main magma and therefore it may migrate to low pressure areas along with other late products. Silica, and the heavy metals (Cu, Pb, Zn, etc.) were also determined in some of the intrusives as they are considered to be important constituents in the pegmatite and/or hydrothermal phases.

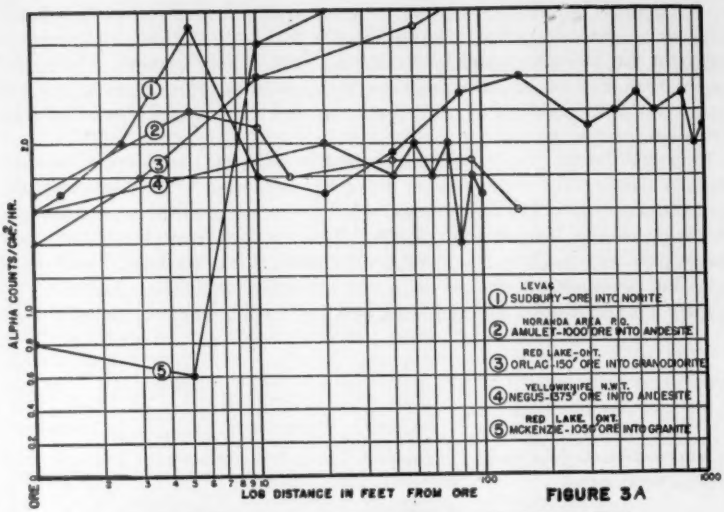


FIGURE 3A

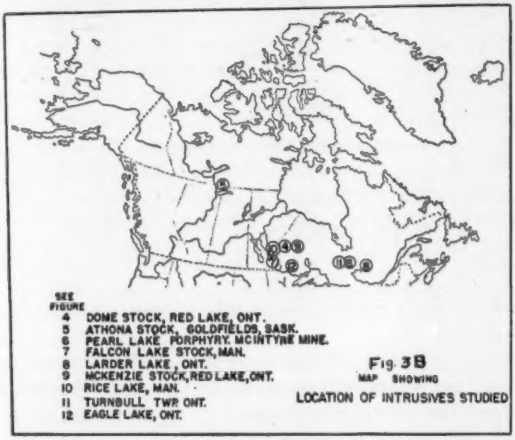

SEE FIGURE
4 DOME STOCK, RED LAKE, ONT.
5 ATHONA STOCK, GOLDFIELDS, SASK.
6 PEARL LAKE PORPHYRY. MCINTYRE MINE.
7 FALCON LAKE STOCK, MAN.
8 LARDER LAKE, ONT.
9 MCKENZIE STOCK, RED LAKE, ONT.
10 RICE LAKE, MAN.
11 TURNBULL TWP. ONT.
12 EAGLE LAKE, ONT.

Fig. 3B
MAP SHOWING
LOCATION OF INTRUSIVES STUDIED

SAMPLING.

Reasonably fresh and unaltered rock specimens are taken from rock outcrops spread statistically over the surface of the intrusive. Each sample, apart from those from the McIntyre Mine which were 3 × 7/8 inch drill-core specimens taken from the underground workings, is composed of a number of rock chips taken at random over the surface of an outcrop. Such samples are believed to be more representative than a single rock sample. The locations of the samples analyzed are shown on all the figures.

Assaying.—Alpha counting methods were used to determine the relative amounts of the radioactive elements of the uranium, thorium, and actinium series in the samples. Alpha-counting eliminated any spurious effects that might have been caused by changes in the concentration of such radioactive isotopes as K^{40} (emits only beta and gamma rays) which might not crystallize late from the magma.

Three different principles were applied in assaying the samples for their alpha activity. The first was an ionization chamber with a photographic recording system (11, 12); and the second was a quantitative photographic technique used by Daniels (4). Both of these methods were rather laborious. To simplify and speed up the work, a third method was used and consisted of an alpha scintillation counter with an automatic recording device. This counter has an effective counting area of 67 sq cm and when the samples were

TABLE 3.

Figure	Name	Location	Composition	Approx. area	Economic importance	Analysed for
4A, B, C, D, E	Dome Stock	Red Lake, Ont.	Granodiorite	15 sq mi	Ore around east contact	Radioactivity—Zr, SiO_2 heavy metals
5	Athona Stock	Goldfields, Sask.	Variable granitic	½ sq mi	Ore in central part of stock	Radioactivity, Zr
6	Pearl Lake Stock	McIntyre Mine, Ont.	Qtz.-feldspar porphyry	0.2 sq mi	Ore on N. W. boundary	Radioactivity
7	Falcon Lake Stock	S. E. Manitoba	Differentiated basic to acid	3 sq mi	Ore in central part of stock	Radioactivity
8	Larder Lake	Kirkland-Larder Lake Area, Ont.	Syenite	0.5 sq mi	Ore on north and S. W. boundaries	Radioactivity, Zr
9	Gold Eagle Stock	Red Lake, Ont.	Granodiorite	1.0 sq mi	Ore around eastern boundaries	Radioactivity
10	Rice Lake batholith	Eastern Man.	Qtz. diorite	Large intrusive area investigated 6 sq mi	Ore around eastern boundaries	Radioactivity, SiO_2
11	Turnbull Stock	Turnbull Twp., Ont.	Granite	0.5 sq mi	No ore	Radioactivity
12	Eagle Lake Stock	Eagle Lake Area, Ont.	Granite	8 sq mi	No ore	Radioactivity

run for periods of one hour they were found to be reproducible to plus or minus 15 percent.

Also used were chemical analyses to determine the silica content, spectrographic analyses, using internal standards, to determine the relative quantity of zirconium, and the colorimetric method, using dithizone, to determine the relative quantity of the heavy metals.

Field Examples.—The following map shows the location of the intrusives studied and Table 3 gives the salient points with regard to each.

The Dome Stock.—A plan of this stock is shown on Figure 4A where it can be seen that four main gold-ore occurrences are located around its eastern margins. A great deal of exploration has been done in other parts of the stock but nothing of importance has been found.

Sixty samples taken at random over the surface of the intrusive were ana-

lyzed for radioactivity, zirconium, silica, and heavy metals.[5] The results of these analyses are shown on Figure 4, Parts B, C, D, and E. A reasonably complete discussion will be attempted on the interpretation of the analytical results for this stock. The eight remaining field examples will be discussed in detail only insofar as they enlarge significantly on the basic ideas.

Referring to the diagrams it can be seen that there is a concentration of radioactivity, zirconium, silica, and the heavy metals in the eastern part of the stock in the vicinity of the ore bodies. Such concentrations could be explained by movement of late crystallizing solutions. If so, what caused this movement? Many geologists in the district believe that there is a major fault zone lying close to the eastern margins of the stock. No definite proof of such a fault is at hand because the area is covered by the waters of Red Lake. However, a major structure known as the East Bay fault occurs a short distance to the northeast and if projected along its strike south-west under the lake, it would pass close to the eastern boundary of the intrusive (8). It should be emphasized here that the concentrations of late crystallizing products in the stock may be only indirectly related to ore. Horwood (8) has shown that there are two periods of mineralization in Red Lake which are substantiated by temperature measurements (Table 2). Both the high and low temperature (early and late) solutions were, however, believed to be controlled by the East Bay fault structure or its subsidiaries.

It should be mentioned here that the plunge of an intrusive may have considerable influence on the distribution of the late constituents. For instance, it would be expected that the late fluid products would rise to the hanging wall side. In such event, the changes in composition of the Dome Stock could be controlled by the plunge rather than by structure, as suggested above. In the case of the Dome Stock, the plunge is believed to be to the west (8). Admittedly, the evidence for this plunge is rather meager but, if valid, the concentrations should theoretically be to the west rather than to the east. Nevertheless, it should be remembered that the only motivation of these late products to the hanging wall side of a plunging stock is the difference in specific gravity of the solid and liquid fractions. If the specific gravity difference is small then migration will be slow. On the other hand, if a major structure exists near at hand there could be a considerable differential pressure between the magma and the fault area such that the late solutions would be forced out of the cooling intrusive at a considerable rate. Such an action would counteract any migration of the solutions to the hanging wall due to specific gravity differences.

The country rock around the Dome Stock is mainly basic lava. There is an important possibility that there has been greater assimilation of the lava in the western part of the intrusive than in the eastern part which would account for the compositional differences that we have noted. This could conceivably be the case, particularly if the stock plunges to the west so that blocks of lava could break loose from the hanging wall and, having a higher specific

[5] Heavy metal analyses by R. A. Freberg, Unpublished M.A. Thesis, University of Toronto, 1951.

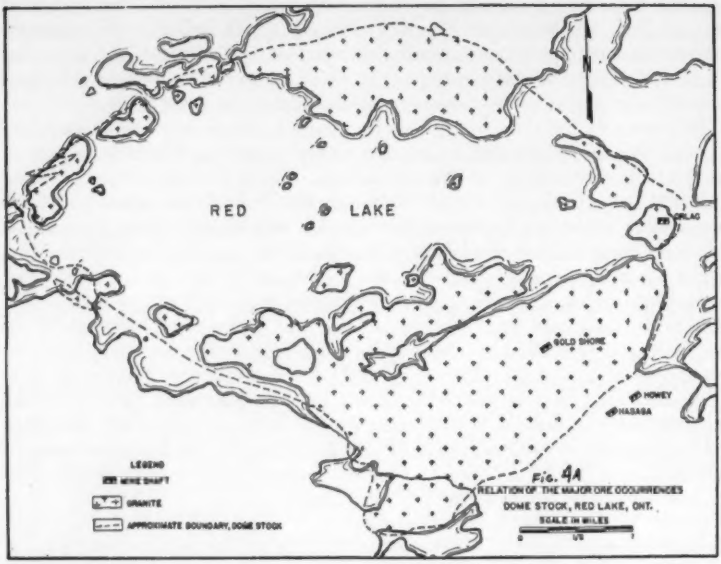


Fig. 4A
RELATION OF THE MAJOR ORE OCCURRENCES
DOME STOCK, RED LAKE, ONT.

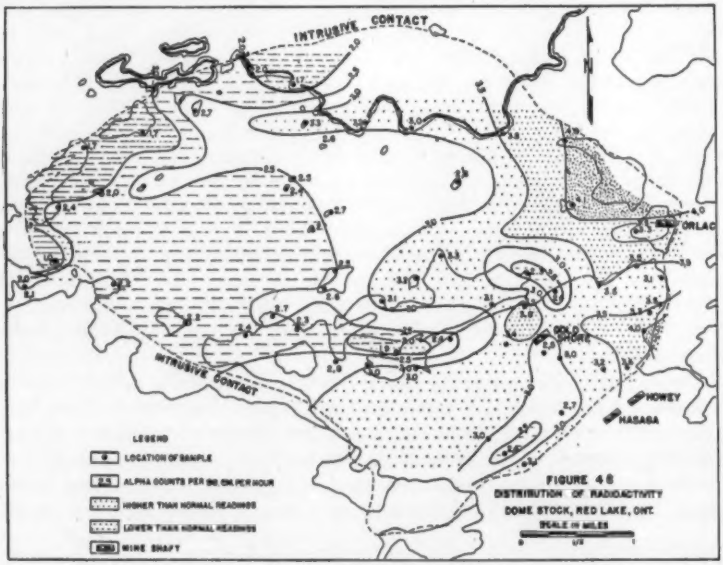


FIGURE 4B
DISTRIBUTION OF RADIOACTIVITY
DOME STOCK, RED LAKE, ONT.

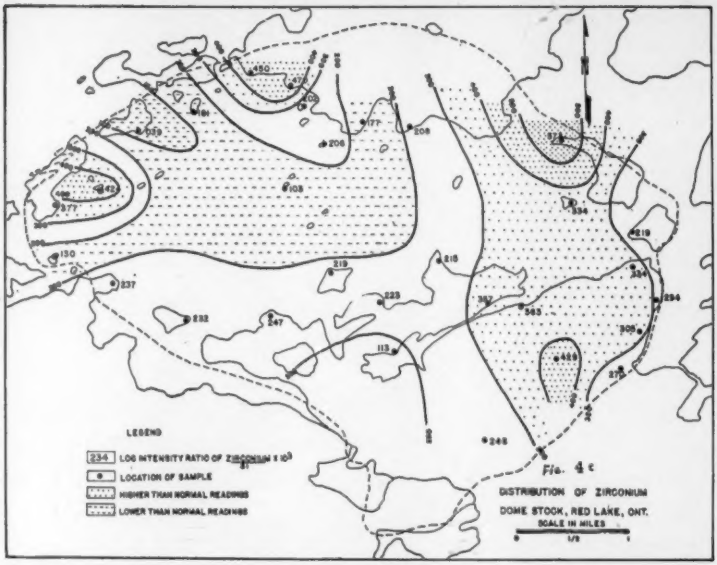

LEGEND
234 LOG INTENSITY RATIO OF ZIRCONIUM x 10³
LOCATION OF SAMPLE
HIGHER THAN NORMAL READINGS
LOWER THAN NORMAL READINGS
DISTRIBUTION OF ZIRCONIUM
DOME STOCK, RED LAKE, ONT.
SCALE IN MILES

Fig. 4 c

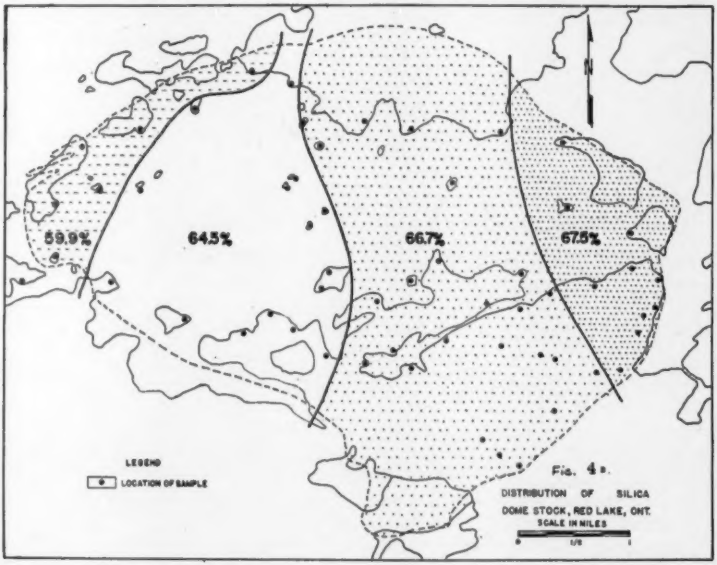

59.9%
64.5%
66.7%
67.5%
LEGEND
LOCATION OF SAMPLE
DISTRIBUTION OF SILICA
DOME STOCK, RED LAKE, ONT.
SCALE IN MILES

Fig. 4 b.

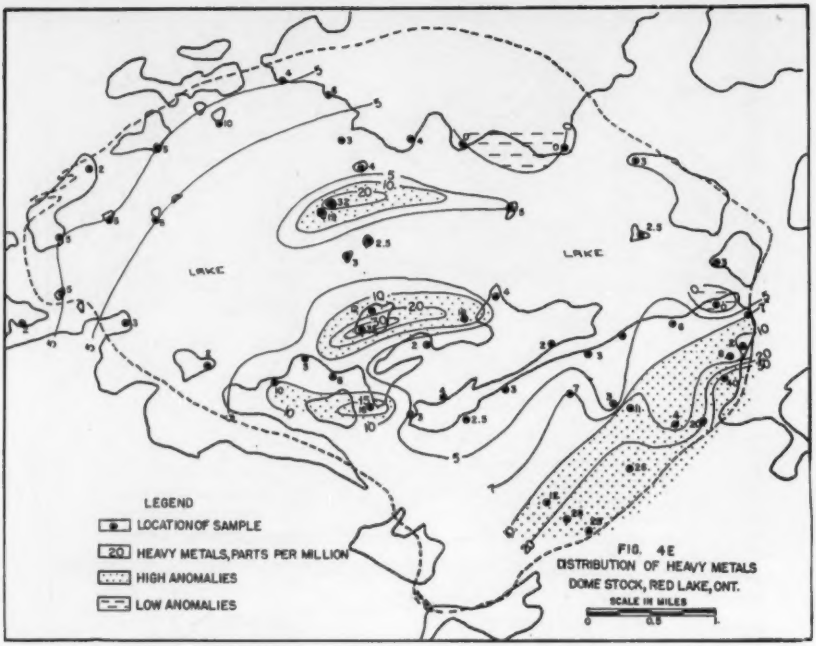


FIG. 4E
DISTRIBUTION OF HEAVY METALS
DOME STOCK, RED LAKE, ONT.

gravity, could sink into the intrusive in that area. However, only a few inclusions were noted in the granite and they did not appear to be any more abundant in the western part of the intrusive than in any other part around the contacts. Further, the inclusions, although somewhat altered, were far from being assimilated. It is doubtful, therefore, that this regular compositional change could be due to assimilation.

It is noteworthy that the zirconium and radioactivity results are only in general agreement. The differences in distribution may be real or the inherent errors in obtaining small representative samples added to the basic errors in the analytical methods themselves (−15% for the alpha counting) may account for the minor discrepancies.

The large difference in the silica content from each side of the Dome Stock is indeed surprising. Assuming that our analyses are correct, it makes one wonder as to the value of analyses which are taken to two places of decimals and held to be the composition of an intrusive when only a few samples are taken from one particular area or another of an intrusive. Quite possibly more rapid analytical methods on a greater number of samples would give a closer approximation of the true composition.

Athona Stock.—This stock appears to have been formed not by intrusion of granitic material but by the granitization of sediments. The reader will be

spared the usual evidence. Low-grade, gold-quartz ore occurs in the form of an irregular boxwork at the Athona Mine in roughly the central part of the stock. The exact location in relation to the boundaries is not known as contacts are indefinite and the general outline of the stock is further obscured by Athabaska Lake. A broad zone of higher-than-normal radioactivity surrounds the main ore zone as shown on Figure 5 and could quite clearly be used as a guide to the ore.

It is suggested that during the high-grade metamorphism and granitization that took place in this area (1, 3), the more mobile products, such as silica and the radioactive elements, migrated to a low-pressure area presently manifested by the ore fracture zone. Zirconium analyses, on the other hand, showed practically no agreement with the radioactivity picture and it is suggested that zircon did not go into solution and was therefore unable to migrate.

Pearl Lake Porphyry.—A plan view of the porphyry on the 1,875′ level of the McIntyre Gold Mine is shown on Figure 6 (13). The figure shows a broad zone of high radioactivity associated with the main ore shear and fracture zone which occurs on its northwest flank. This was the smallest intrusive investigated and on this scale it can be seen that there was a sharp decrease in radioactivity in the intrusive within 10 to 100′ of the contact. This may be due to chilling at the contact or to the effects of later hydrothermal alteration as suggested earlier.

Falcon Lake Stock.—Brownell (2), shows clearly that this is a multiple and composite intrusive. A pipe-like, fracture zone carrying gold-quartz mineralization occurs in granodiorite in the central part of the body. By passing the complexities so adequately treated by Brownell and considering the mass as a simple structure, as would probably be done in prospecting, it is evident from Figure 7 that the zone of highest radioactivity straddles the ore-pipe as indicated on the figure by the shaft symbol. Two additional small gold deposits occur near the shaft but they are located well within the higher-than-normal radioactive area.

Larder Lake Syenite.—Referring to Figure 8, it will be observed that the Omega Mine is located in the Kirkland Larder break which is one of Canada's great ore controlling structures. There has been pre-ore, ore, and post-ore movement on the break and it is likely that this structure was in existence at the time of intrusion of the Larder Lake syenite. A high radioactive anomaly occurs in the northern part of the intrusive and suggests that there was flow from the intrusive in the direction of the fault.

This example is interesting because another high anomaly occurs in the south along the shores of Larder Lake. Thomson (23), has mapped a fault in this area but its extent is unknown owing to the water coverage. It would be expected that a magma intruding the complexly folded and faulted Archean might develop large-scale leaks in several areas around its contact. Early leaks might take the form of dikes of the same composition as the magma, those coming later as pegmatites and hydrothermal veins, whereas the general flow trend within the magma is indicated by the compositional differences as the magma differentiates.

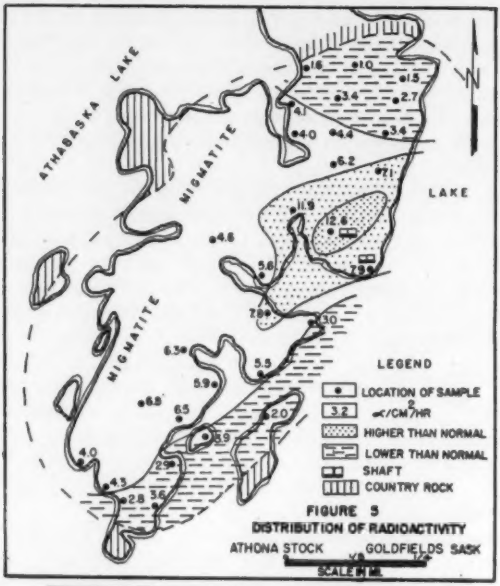


FIGURE 5
DISTRIBUTION OF RADIOACTIVITY
ATHONA STOCK GOLDFIELDS SASK

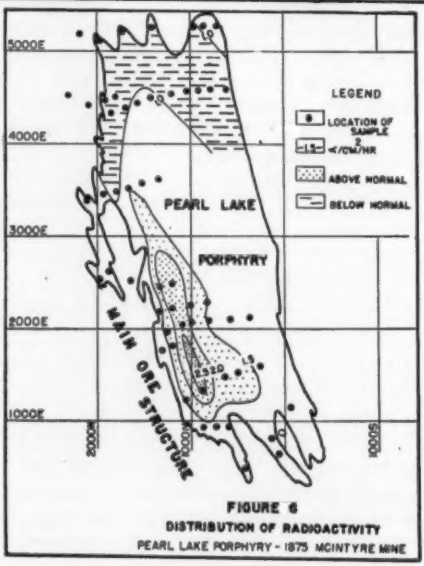


FIGURE 6
DISTRIBUTION OF RADIOACTIVITY
PEARL LAKE PORPHYRY - 1875 MCINTYRE MINE

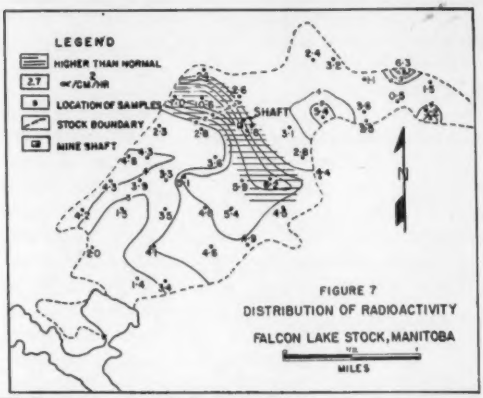


FIGURE 7
DISTRIBUTION OF RADIOACTIVITY
FALCON LAKE STOCK, MANITOBA

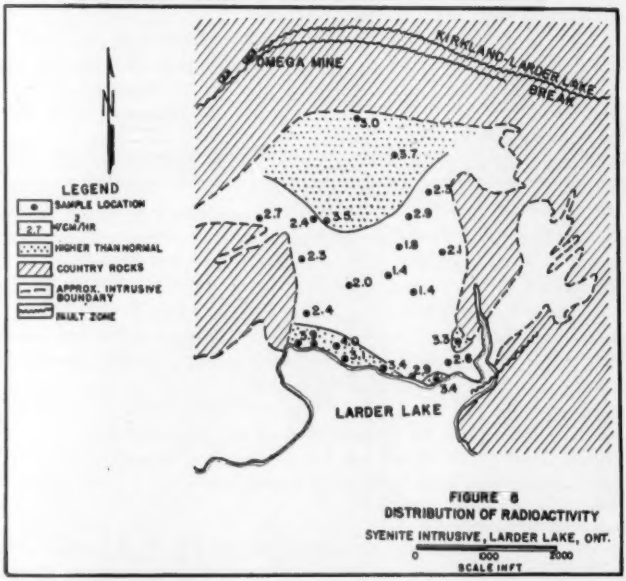


FIGURE 8
DISTRIBUTION OF RADIOACTIVITY
SYENITE INTRUSIVE, LARDER LAKE, ONT.

An ore body occurs near the southwest contact of the syenite of the map area shown on Figure 8. Unfortunately, insufficient samples were taken to determine if this southern anomaly builds up in that direction.

Zirconium determinations were made for the samples from this intrusive. The zirconium distribution agreed almost exactly with the radioactive picture.

McKenzie–Gold Eagle Stock.—Two gold-bearing ore bodies at the McKenzie Mine and the Gold Eagle Mine (now worked out) are associated with

this intrusive. The vein system at the McKenzie Mine is in a rather complex system of faults and fractures which have an average strike north-south and dip 35° west. The Gold Eagle vein zone has a strike of S. 65° E. and has an average dip of 52° S.W.

Figure 9 shows the results of the radioactive measurements. A striking feature, as shown by the isoradioactive lines, is that the radioactive distribution is parallel to both the McKenzie and Gold Eagle ore structures. Of equal significance is the fact that there is an increase in the radioactivity of the granodiorite towards both of these structures. It must be made clear that this radioactive concentration only indicates the possible location of favorable structures; it may have nothing whatsoever to do with the mode of ore introductions.

Parts of both vein systems are in the granitic rock, and the possibility of the intrusive itself supporting an active and open structure to which late solutions can move may be questioned. It must be remembered that the intrusive at this stage is essentially solid and although open structures probably do not form, relatively low-pressure areas within the intrusive are believed to exist and to act in much the same way as open fractures.

Rice Lake Batholith.—A batholith in the Rice Lake area (22) was selected for investigation for two reasons: first, it has a nose-like feature along its eastern extremity, which has a number of small gold deposits spatially related to it; and second, it has a more basic composition than the other intrusives, being on the average a quartz diorite.

Specimens covering an area three by two miles of the nose-like embayment were analyzed for their radioactive and silica content. Figure 10 shows that there is a statistical increase in the radioactive content of the intrusive going from west to east towards the mineral occurrences. The concentration, however, is not marked. In fact, the radioactivity of this intrusive, being of a more basic composition, is much lower than the granitic intrusives. For this reason, radioactive migrations may not be clearly exemplified.

Figure 7 also shows the results of the silica analyses. The specimens were assembled into four groups on the assumption that the silica would increase eastward. It can be seen from the figure that the silica changes from 64 to 71 percent going from west to east. (The rock was classified by Davies [6] as quartz diorite, mainly on the composition of the plagioclase.)

Turnbull Stock.—There are no known mineral deposits associated with this stock. There may be a number of explanations for this situation, among which are the following:

(a) there may have been a paucity of ore minerals in the original magma.
(b) ores may have been present but the composition of the magma may have been unfavorable for them to enter into the hydrothermal solution phase.
(c) there may be a lack of favorable structures to act both as channelways and as housing for the ore.
(d) ore may have been associated with the parts of the intrusive that have been eroded away.

[6] Personal communication, J. F. Davies, Manitoba Dept. of Mines.

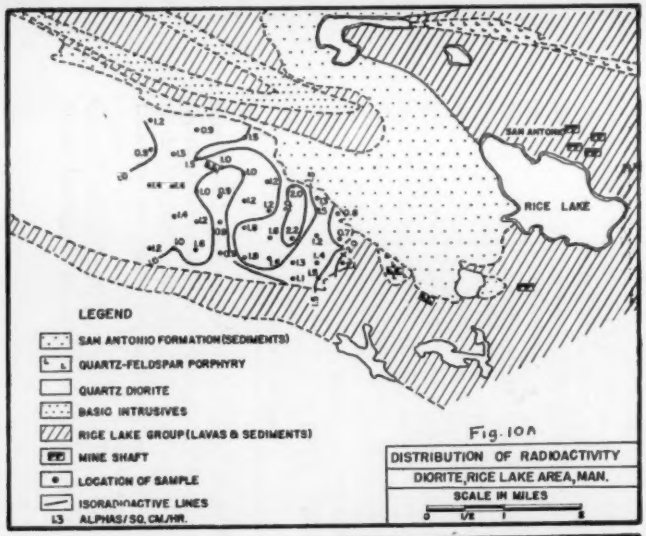


Fig. 10A

DISTRIBUTION OF RADIOACTIVITY
DIORITE, RICE LAKE AREA, MAN.
SCALE IN MILES
0 1/2 1 2

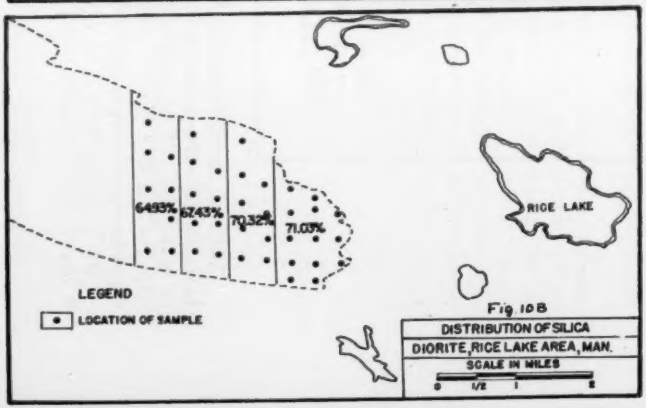


Fig 10B

DISTRIBUTION OF SILICA
DIORITE, RICE LAKE AREA, MAN.
SCALE IN MILES
0 1/2 1 2

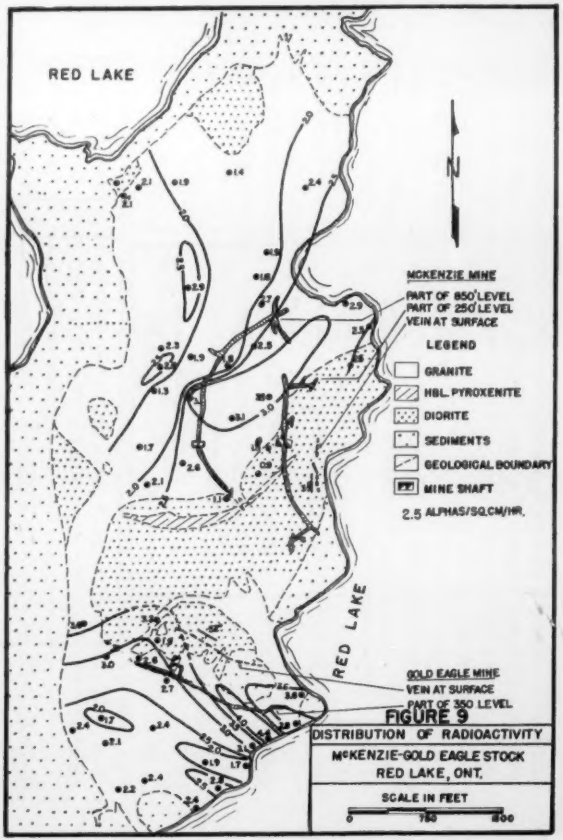
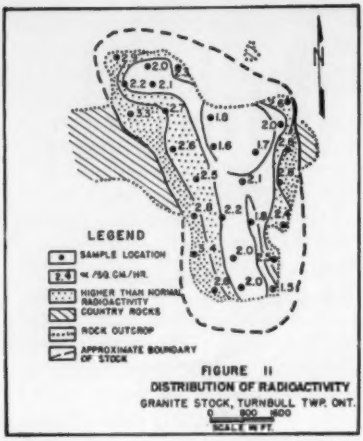
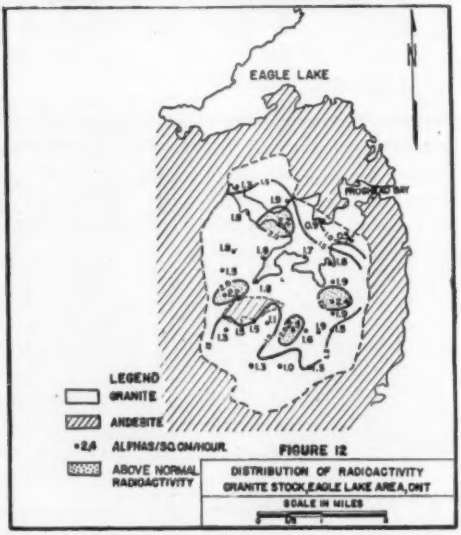


FIGURE 9

DISTRIBUTION OF RADIOACTIVITY
McKENZIE-GOLD EAGLE STOCK
RED LAKE, ONT.
SCALE IN FEET
0 750 1500





Although the north and south extremities are covered by deep drift, Figure 11 indicates that the radioactivity in the Turnbull Stock is concentrated around its boundaries. If no prominent structures exist in the neighborhood of the intrusive and if it has no prominent plunge, then peripheral concentration might be expected, as suggested for Part B, Figure 2.

Eagle Lake Stock.—This stock was also selected for investigation because it has no known mineral deposits associated with it. As suggested above,

there are numerous reasons why some intrusives such as this one are "barren." One of the reasons certainly could be that there were no favorable structures near at hand and consequently there was no particular movement and concentration of the late solutions believed so necessary for ore formation. Figure 12 shows the radioactive determinations made on the surface samples. There appears to be no concentration of radioactivity on any one area of this stock which in turn suggests that there was no movement of the late solutions at this erosion horizon. A lack of peripheral concentrations may be explained by erosion cutting below its effective level (Part B, Fig. 2). It may follow from this discussion that there were no favorable structures in the vicinity and/or that the stock has no plunge.

Radioactive distributions of these last two types may be helpful in eliminating intrusives from extensive prospecting.

CONCLUSIONS.

1. Stocks and batholiths of igneous or sedimentary origin are found to have a zone of higher-than-normal radioactivity in the vicinity of ore structures. Intrusives with no important structures close at hand have no such concentration. The determination of the distribution of the radioactive elements, therefore, can be used as a general guide to ore structures.

2. The distribution of zirconium, silica, and the heavy metals can be used in much the same way as radioactivity. Zirconium, however, appears to be less reliable as a structural indicator in granitized sediments, whereas in more basic rocks, silica is more critical than radioactivity.

3. The technique is believed to be of practical value as it enables the prospector to restrict his detailed work to relatively small areas around an intrusive body. Furthermore, if no major concentrations are found, the intrusive may well be eliminated from detailed prospecting.

4. There is good evidence that quartz and the radioactive minerals crystallize at a late stage from a magma. The similarity in the distribution of silica, radioactivity, and zirconium in igneous intrusives suggests that the accessory mineral zircon crystallizes late. The lack of agreement between the zirconium and radioactivity in the Athona stock might be used as a criterion for granitization.

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June 9, 1952.

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SOURCES OF ERROR IN THE DECREPITATION METHOD OF STUDY OF LIQUID INCLUSIONS.

THOMAS EDWIN STEPHENSON.

ABSTRACT.

Discussed are two sources of error in the decrepitation method of study of liquid inclusions. Certain minerals were found to contain inclusions that leaked prior to breaking, with the result that the decrepitation temperatures recorded for these minerals exceeded the visually determined temperatures of filling by as much as 150 degrees Centigrade. Samples of other minerals studied contained secondary inclusions which formed at lower temperatures than primary inclusions in the same sample. The secondary inclusions in these samples began to decrepitate at lower temperatures than the primary inclusions and continued to decrepitate as heating continued, with the result that the start of decrepitation of the primary inclusions was masked.

Neither of the sources of error can be detected by decrepitation tests alone. Decrepitation tests, therefore, must be preceded by optical examinations both at room temperature and with the heating stage. The optical examinations would have to be done in such detail as to eliminate the need for decrepitation tests.

Discussion is included which indicates the necessity for consideration of these sources of error in the interpretation of the results of any study of liquid inclusions.

INTRODUCTION.

THE study of liquid inclusions to determine the temperature of formation of minerals has received considerable attention in recent years. Two general methods of study have been employed. The first and older method employs a heating stage on a microscope with which the inclusions are studied optically. The second method employs a system that detects and records the explosions of inclusions—the so-called decrepitation method. The theory relative to each of the methods has been thoroughly described in the literature and need not be repeated here. The reader's attention is called especially to the papers by Ingerson (3),[1] Bailey and Cameron (1), Scott (6), Kennedy (4), and Smith et al. (7).

The writer originally undertook the optical study of liquid inclusions in quartz veins found in several of the iron formations of the Lake Superior District. During the course of this study, inclusions were encountered that were too small for optical study. In an attempt to work with these inclusions, an apparatus was developed to utilize the decrepitation method of study. Anomalous results encountered in the decrepitation studies led the writer to investigate the decrepitation method itself. The present paper summarizes the results of this investigation.

[1] Numbers in parentheses refer to Bibliography at end of paper.

ACKNOWLEDGMENTS.

This study was financed in part by grants from the Wisconsin Alumni Research Foundation. Professors E. N. Cameron and S. A. Tyler of the University of Wisconsin devoted considerable time to critical discussions of the problem and offered many helpful suggestions. Robert Rowe, P. L. Weis, and S. W. Bailey, associates at Wisconsin, provided much of the optical data used in the study. Professor Verner Soumi and Mr. John Rose of Wisconsin, and Professor Karl Larsen of Lafayette College, provided considerable assistance and advice in the development of the decrepitation apparatus.

PROCEDURE.

The apparatus used and the procedure followed for the optical work was essentially the same as that described by Bailey and Cameron (1, p. 634).

The apparatus used for decrepitation work varied somewhat as the work progressed, but the overall results were not materially affected by the changes.

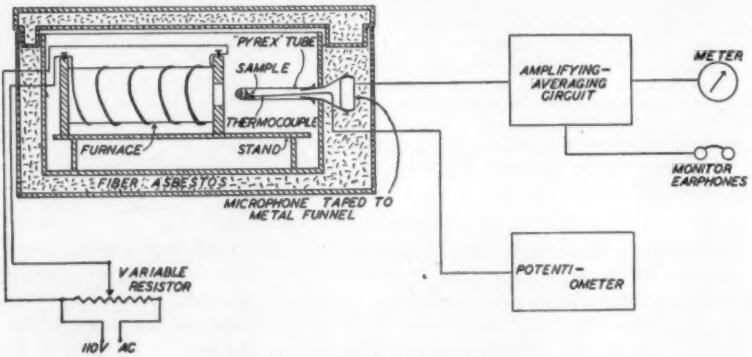

FIG. 1. Decrepitation apparatus.

Originally the noise of the bursting inclusions was picked up by a crystal microphone, amplified by a three-stage amplifier and fed into a ratemeter that counted the bursts. The amplifier was later altered to an amplifying- averaging circuit, the output of which deflects the pointer of a meter. The amount of deflection is a function of the frequency of explosion of the inclusions.

Figure 1 is a sketch of the decrepitation apparatus. The material to be studied is ground and screened to +40–60 mesh. The sample—about a thimbleful—is then placed in the test tube and the test tube placed over the end of the funnel. The furnace is then placed over the test tube and the lid placed on the box. Temperature control is maintained by a thermocouple inserted directly into the sample.

As the temperature is increased, the frequency of exploding inclusions as measured by the meter is recorded against temperature to produce a decrepi-

graph as described by Scott (6) and Peach (5). The rate of heating in most cases was about 20° per minute. Split samples gave essentially the same results with the thermocouple either suspended in the sample or with it touching the bottom of the tube, so it was concluded that errors in temperature measurement due to lag in heating between test tube and sample were negligible.

DISCUSSION OF INVESTIGATION.

Statement of Problem.—During use of the decrepitation method, two sets of seemingly anomalous results were encountered which warranted investigation. When the apparatus was first set up, decrepitation tests were run on many of the quartz vein samples that had previously been studied optically. The general agreement of results by the two methods was far from satisfactory (Table 1). Later, when siderite from the Michipicoten District, Ontario, was studied, temperatures of decrepitation as high as 400° C were encountered. These seemed far too high to be consistent with possible modes of origin of the siderite.

TABLE 1.

TEMPERATURE DATA FOR QUARTZ SPECIMENS.

Location of specimen	Decrepitation temp. (° C)	Visual temp. range (° C)
Marquette Range		
Kruse Mine	210–230	140–308
Iron Mtn. Lake Mine	200	202–212
Etna Mine	130	290
Etna Mine	200	270
Menominee Range		
Crystal Falls	210–230	250–275
Crystal Falls	200	245
Crystal Falls	200	265
Milly Mine	120	130–135
Mesabi Range		
Columbia Mine	300	170–185
Columbia Mine	130	120–340

Investigation of Extremely High Temperatures of Decrepitation.—The high decrepitation temperatures of siderite were investigated first. It was thought that possibly a study of carbonates in general might shed some light on the problem. The first step was a study of selected specimens of limestone and dolostone from the stratigraphy collection at Wisconsin. Temperatures of decrepitation varied from 50° C for a coarsely crystalline sample of the Franklin limestone to 390° C for a specimen of the Frontier limestone. Again, the results obtained seemed to be out of line with the supposed geologic histories of the rocks.

Meanwhile research was being done at Wisconsin on the thermoluminescence of limestones. Since thermoluminescence is a function of temperature, it was thought that there might be some correlation between the thermoluminescence and the decrepitation of limetones. During an unsuccessful attempt to relate the two properties, the occasion arose to heat to 400° C a fragment of Lakeside limestone whcih normally decrepitated sharply at

250° C. After being held at 400° C for several hours, the fragment was allowed to cool, and a portion of it was crushed and placed in the decrepitation apparatus. The specimen no longer decrepitated at 250° C, but at 390° C, or very nearly at the temperature to which it was preheated.

A similar technique was then employed on specimens of calcite with the same results. It was found that the specimen could be preheated in a large fragment or in a powder without altering the results. Also, the rate of preheating and cooling of the specimen could be varied greatly without affecting the results.

On the assumption that the results of the preheating technique might be related to the cleavage in calcite, samples of quartz were run. Again, the temperature of decrepitation was found to lie within twenty degrees of the preheating temperature. Fluorite, on the other hand, did not follow the pattern in all cases. It was discovered however, that much fluorite literally explodes unless heated very slowly, even after preheating.

The next step was to study samples of quartz, calcite, and fluorite optically with the heating stage. Vapor bubbles in inclusions were measured and then each specimen was heated until the bubbles in the inclusions present disappeared and the liquid filled the cavities. The temperature of filling was then exceeded by fifty degrees and the specimen was allowed to cool. Some of the inclusions were destroyed by this procedure. The vapor bubble reappeared in others, however, and, as was suspected, was larger than it was before heating. When the temperature of filling was then exceeded by one hundred degrees and the specimen allowed to cool, more inclusions were destroyed and the vapor bubbles were further enlarged in those remaining. Although some inclusions appeared to be interconnected or adjacent to fractures, others which leaked (none was observed which did not leak) showed no visible signs of fractures.

A combined optical-decrepitation study of a large crystal of halite provided the key to the problem of abnormally high temperatures of decrepitation. Small fragments of the crystal were studied optically. All of them contained large cubic or rectangular inclusions with extremely small vapor bubbles. As would be expected, the vapor bubbles were obviously enlarged after the temperature of filling was exceeded. Crushed fragments of the crystal were then placed in the decrepitation apparatus. The temperature of decrepitation at the normal rate of heating was 170° C—110 degrees above the optical temperature of disappearance. By slowing down the rate of heating to 20° per minute the temperature of decrepitation rose to 280° C. At a temperature gradient of 10° per minute, the halite did not reach sustained decrepitation up to a temperature of 500° C—the practical upper limit of the apparatus.

The results with the halite crystal indicate that leakage is a factor in certain of the abnormally high temperatures of decrepitation. Apparently, as the specimen is being heated, leakage takes place soon after the inclusions fill with liquid. If the rate of heating is rapid, the leakage is able to relieve the pressure only up to a certain point, the internal pressure builds up and the cavity breaks. If the rate of heating is slow enough, the leakage continues to relieve the internal pressure of the inclusions—at least to the upper limit of the apparatus used in this investigation. It was deemed impractical to attempt

using a heating rate faster than 40° per minute because of the probable error in temperature measurement which would be introduced.

A large crystal of calcite was tested using a variable heating rate. At 40° per minute, the temperature of decrepitation was 140° C. At 20° per minute it was 170° C and at 10° per minute 220° C. The overall effect was the same as with halite, but the specimen still decrepitated when heated slowly. On the other hand, results on quartz specimens tested in the same manner were not affected by varying the rate of heating. Results on fluorite were also unaffected, except that fluorite tended to explode at a low temperature when heated faster than 20° per minute. Thus, it would seem that leakage affects the results of decrepitation only in certain minerals, since quartz and fluorite, which were found to leak readily when preheated, are apparently unaffected by variable rates of heating. It is not improbable, however, that the effect of leakage would appear in decrepitation tests run on some specimens of quartz and fluorite. Further proof of the effect of leakage on calcite and also sphalerite will be pointed out later.

Secondary Inclusions.—It was pointed out earlier that results of decrepitation tests compared unfavorably with optical results obtained from certain quartz specimens. This comparison suggests interference of secondary inclusions in the instances where the decrepitation temperatures are lower than the optical temperatures. These results in themselves are inconclusive, however, in that the quartz studied displayed no growth structures or crystal faces that would aid in the distinguishing of primary and secondary inclusions. The inclusions selected for optical determinations were, in so far as was possible, ones that were not bounded by possible fractures, and which did not lie in planes with other inclusions.

In order to obtain more conclusive, and at the same time impartial, observations of the effect of secondary inclusions, Dr. Cameron suggested testing specimens which had been thoroughly examined optically during research of liquid inclusions at Wisconsin. Samples were given to the writer bearing only a number for identification. Decrepitation tests were run on these samples and, upon completion of all the tests, optical and decrepitation temperatures were compared. Table 2 is a tabulation of results for all specimens run in this manner.

It will be noted that the decrepitation temperatures for the pegmatite minerals are, for the most part, lower than the optical temperatures. In each case, the decrepitation runs were continued to approximately 500° C in an attempt to pick a second break in the decrepigraph. In no case was a second break apparent, let alone significant—even when the curve was studied knowing the optical temperature. The fact that the optical temperatures were the result of many determinations and that the specimens were known to contain secondary inclusions leads one to conclude that secondary inclusions are responsible for the discrepancies between the results of the two methods. Secondary inclusions along fractures are abundant in these minerals and visual studies have shown that they are prone to fracture at temperatures below the temperatures of filling.

TABLE 2.

TEMPERATURE DATA FOR PEGMATITE MINERALS.

Specimen No.	Mineral	Decrepitation temp. (° C)	Visual temp. range (° C)
A-1a	Garnet	300	301–342
A-1b	Black Tourm.	170 (270?)	216–255
A-8	Beryl	140	232–401
A-9	Beryl	200	288–344
H-3	Beryl	120	341–348
I-3	Beryl	120	318–381
I-4	Beryl	170	312–340
I-16	Beryl	120	120–170*
I-20	Beryl	140	140–200*
I-24	Beryl	170	150–190*
S-1	Quartz	115	347–395
			276–278
S-3	Quartz	200	291–332
S-4	Quartz	140	304–334
S-5	Quartz	190	291–332
S-6	Quartz	110	See S-5
S-8	Beryl	230	248–385
S-9	Beryl	110	207–266
S-10	Beryl	90	196–248
S-11	Spodumene	200	220–300
S-12	Spodumene	280	284–354
S-13	Spodumene	100	194–268
S-15	Beryl	160	315–455
S-16	Beryl	305	315–455
S-17	Beryl	300	292–354
S-18	Beryl	120	180–260
S-19	Beryl	120	See S-17
S-20	Beryl	330	See S-17
S-21	Quartz	100	276–327
S-22	Quartz	150	See S-21

TEMPERATURE DATA FOR SPHALERITE-CALCITE SPECIMENS.

Specimen No.	Mineral	Decrepitation temp. (° C)	Visual temp. range (° C)
R-1	Sphalerite	150	82–90
R-2	Sphalerite and marcasite	260	87–108
R-3	Sphalerite	100	83–102
R-4	Sphalerite	170	77–92
R-5	Sphalerite	150	84–92
R-6	Sphalerite	140	75–80
			100–103
R-7	Sphalerite	160	84–110
R-8	Sphalerite	110	93
R-11	Calcite	205	50–76
R-12	Calcite	225	50–76

* Determinations made on probable secondary inclusions.

The tests run on the sphalerite and calcite were also run to test the effect of secondary inclusions, although the writer did not know this until after the tests were run. Actually, however, these specimens served to validate the leakage theory proposed earlier in this paper. Note that with the exception

of specimen R-3 the decrepitation temperature is in excess of the temperature determined optically. The author knows of no plausible explanation of the discrepancies other than leakage of the inclusions prior to breakage.

CONCLUSIONS.

The results of this investigation indicate two sources of error that may be encountered in the decrepitation method of studying liquid inclusions. One source of error is the leakage of inclusions in certain minerals with the result that the mineral decrepitates at a temperature that is higher than the temperature at which the inclusions fill with liquid. The second source of error, which might be present in any specimen, is secondary inclusions. A specimen in which secondary inclusions have formed at a lower temperature than primary inclusions will begin to decrepitate at the lower temperature. As heating is continued, the secondary inclusions continue to decrepitate, masking the start of decrepitation of the primary inclusions.

The effect of these sources of error is serious because, in most cases, neither leakage nor secondary inclusions can be detected from decrepitation tests alone. It is necessary, therefore, to maintain strict optical control over decrepitation experiments. Optical studies made by the author and by Bailey, Rowe, and Weis (oral communications) indicate that the possibility of either source of error could not be eliminated by studying only a few specimens in each suite. It is felt that optical work would have to be done in such detail as to eliminate the need for decrepitation tests.

Grogan and Shrode (2) report having found secondary inclusions in fluorite which had formed at higher temperatures than primary inclusions. Results of the preheating technique indicate that such a relationship is improbable. The preheating experiments suggest that primary inclusions which were formed at a given temperature would leak if exposed to a higher temperature. Secondary inclusions formed at the higher temperature would then react essentially the same as the primary inclusions so altered.

Aside from the possible errors in decrepitation results, this investigation also brings to light certain facts that should be considered in terms of the possible geologic history of certain inclusions, particularly those formed at high temperatures and high pressures. In the case of an inclusion formed at moderate depth and at an elevated temperature, it is fairly reasonable to assume that cooling would precede the release of pressure. As the inclusion cooled and the vapor bubble formed, a partial vacuum would be established within the inclusion. In the case of minerals that leak readily, it is possible that liquid could be forced into the inclusion. The effect would be to reduce the size of the vapor bubble. The temperature of formation of such an inclusion as measured by either method of decrepitation would be lower than the actual temperature of formation. The error involved would be in addition to error introduced by pressure at the time of formation. This idea was presented by Kennedy (4). He subjected a specimen to high pressure and was able to reduce the size of the vapor bubbles in inclusions.

It is also possible that an inclusion in equilibrium at an elevated tempera-

ture and pressure might be subjected to a sudden lowering of pressure due to dilatancy. In a case of this type, the result would be essentially the same as exceeding the temperature of filling in the laboratory. Material would tend to leak from the inclusion and the vapor bubble formed upon cooling would be too large. Temperature determinations on inclusions of this sort would be higher than the actual temperatures of formation.

In view of the experimental evidence presented here, and of the geologic possibilities contingent upon this evidence, the conclusion seems justified that the sources of error discussed above should receive serious consideration in the interpretation of the results of any study of liquid inclusions.

JONES & LAUGHLIN STEEL CORP.,
VIRGINIA, MINN.,
May 22, 1952.

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URANIUM–COPPER DEPOSITS, RUM JUNGLE, AUSTRALIA.

C. J. SULLIVAN AND R. S. MATHESON.

ABSTRACT.

Uranium mineralization was discovered in association with copper minerals at Rum Jungle in September, 1949. Investigations carried out since that time, and which are still proceeding, have led to the discovery of additional occurrences, and have shown that the field is likely to prove an important one.

The prospects are mainly uranium-copper deposits, but autunite deposits, which are poor in copper, also occur.

In addition, radioactivity has been found in a bed of conglomerate over a length of 2.5 miles. No uranium minerals have yet been positively identified from the outcrop of this conglomerate, which shows no sign of sulfide mineralization.

This paper presents a preliminary account of the geology and type of mineralization in the Rum Jungle area.

SITUATION.

THE Rum Jungle uranium–copper deposits are situated approximately 55 miles south-southeast of the port of Darwin, Northern Territory, Australia, and are 2½ miles northeast of the Rum Jungle Siding, which is 56 miles by rail south of Darwin.

Rum Jungle is situated in the summer rainfall area and the monsoonal wet season lasts from November to April inclusive.

HISTORY.

Copper was discovered in the Rum Jungle area late in the 19th century, and small parcels of secondary copper ore were mined from shallow open-cuts and shafts. The occurrence of uranium minerals in the area was not known, and the zone of primary mineralization was not adequately tested.

In September, 1949, a prospector, J. White, after reading a handbook on prospecting for uranium issued by the Commonwealth Bureau of Mineral Resources, re-examined the old copper workings and submitted for examination samples that were found to contain torbernite and uranium ochres. The discovery was inspected by Bureau of Mineral Resources geologists and geophysicists in October, 1949, and detailed investigations in the area were commenced by the Bureau in May, 1950.

GENERAL GEOLOGY.

The known uranium deposits are situated on the southern flank of a domal structure in Precambrian meta-sediments, which have been regionally folded and faulted and intruded by granite. The sediments, which consist of interbedded grits, quartzites, pebble beds, conglomerates, breccias, crystalline

limestones and slates (partly carbonaceous and graphitic), are mainly shallow water types, and are assigned to the Brocks Creek Group of Lower Proterozoic age.[1]

The core of the domal structure is occupied by the granitic complex, consisting of granite and granitized sediments. The core is about 10 miles from north to south, and averages about 6 miles from east to west. Quartz veins, representing at least two periods of injection, occur in the area.

Basic dikes, which may be younger in age than the granite, are present. Superficial deposits of soil, alluvium, and laterite, of Recent to Tertiary age, obscure the basement rocks in many parts of the area.

GEOLOGIC STRUCTURE

Both regional and local folding and faulting of the Brocks Creek Group occurred in the area in Precambrian times.

The Rum Jungle domal structure, and also adjoining geologic structures that have been investigated, are folded on approximately north-south axes, and during this period of folding the incompetent slate formations in the Brocks Creek Group were internally folded and marked schistosity and cleavage were developed in them.

Giant's Reef fault (Fig. 1), which intersects the southern end of the Rum Jungle structure, is one of the most striking structural features in the area. It trends northeasterly, has a steep variable dip, and a horizontal displacement of 3¼ miles, the southeastern side being displaced to the southwest. Large quartz reefs occur in places along the line of the fault, which, from the examination of aerial photographs, is known to continue to the southwest for at least 50 miles. Reference to Figure 1 will show that, during faulting, a major east-pitching dragfold developed in the formations of the Brocks Creek Group on the northern side of Giant's Reef. Detailed investigations have shown that the formations north of the fold axis have a general southerly dip, whereas the formations south of it, representing the southeastern limb of the dragfold, are overturned to the northwest. An axial plane shear, parallel to Giant's Reef fault, has developed in the dragfold, and, as will be seen later in this report, one of the authors (R. S. M.) considers it has had an important bearing on ore deposition.

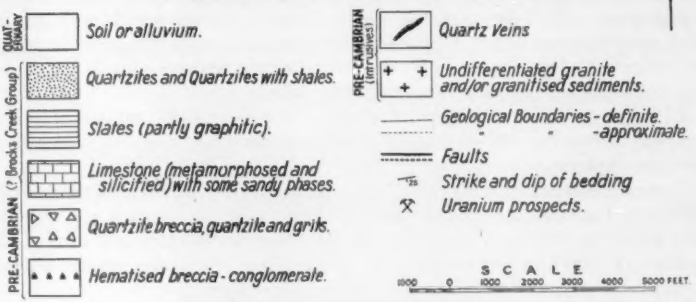
Other major faults parallel to Giant's Reef fault intersect the Rum Jungle structure, and parallel shearing has no doubt developed in many places during this period of faulting.

After the Giant's Reef period of faulting another period of faulting occurred in the area. This system of cross-faults strikes in a north-northeast to northwest direction. These faults have caused displacements of Giant's Reef fault, and consequently also of the axial plane shear of the dragfold associated with it. They are, in part, also occupied by quartz. Some post-ore cross-faults that may belong to this period of faulting, or a still younger period, occur in the area.

[1] Noakes, L. C., A geological reconnaissance of the Katherine-Darwin Region, Northern Territory: Comwlth. Bur. Min. Res. Geol. and Geophys. Bull. 16, 64 pp., 1949.

Figure 1.

GEOLOGICAL MAP
RUM JUNGLE AREA.
NORTHERN TERRITORY, AUSTRALIA.
Interpretation based on regional and detailed mapping by Bureau of Mineral Resources field parties.



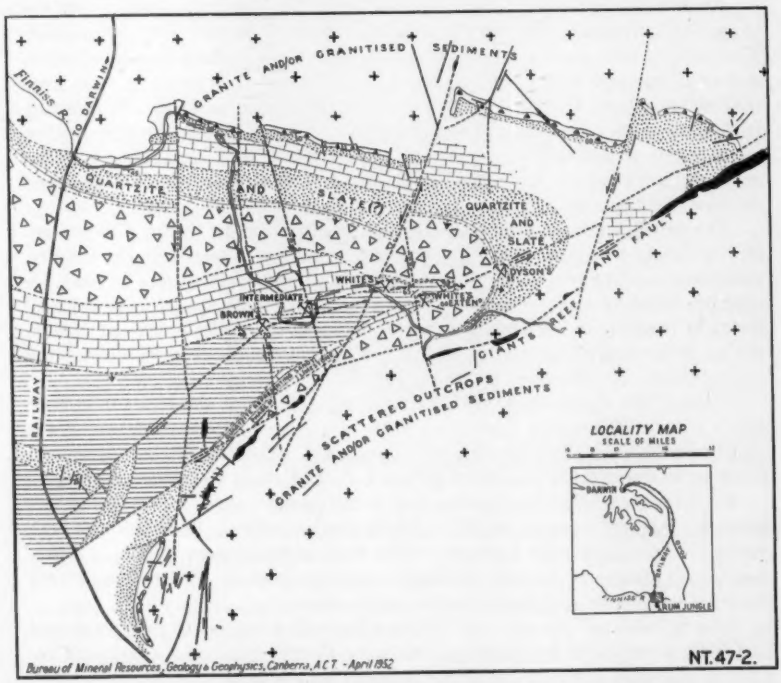


FIG. 1. Geological map Rum Jungle, Northern Territory, Australia.

THE DEPOSITS.

Five uranium prospects, namely, Dyson's, White's Extended, White's, Intermediate, and Brown's prospects, are shown on Figure 1; they occur at irregular intervals along a line trending in a northeasterly direction. Two additional prospects, namely, the Crater and Mt. Fitch prospects, occur outside the map area. With the exception of the Crater prospect, which is associated with a conglomerate bed in a grit formation, and which may possibly be of detrital origin, all deposits are of hydrothermal origin and are closely associated with the carbonaceous slates and graphitic schists.

Exploratory work, which commenced in the area in 1950 and is still in progress, has shown that White's and Dyson's prospects are likely to be the most important deposits.

Copper mineralization is closely associated with the uranium mineralization at White's, Intermediate, and Brown's prospects, but at Dyson's and White's Extended prospects the occurrence of copper minerals is extremely rare. The deposits can therefore be conveniently separated for description on the relative abundance of copper minerals.

At White's prospect, which can be regarded as a type locality for the copper-rich uranium deposits, surface exposures were not very impressive. The country rock slates are fairly widely stained by secondary copper minerals, and small amounts of secondary copper ore were mined in the early days from shallow workings, but little torbernite occurred at the surface. Prospecting work later revealed the presence of uranium ochres, including phosphuranylite, in addition to torbernite, in the oxidized zone. These secondary uranium minerals occurred in association with azurite, malachite, iron oxides, and pseudomalachite and dihydrite (alteration products of torbernite.)

The primary minerals chalcopyrite, bournonite, bornite, pyrite, and uraninite first began to appear below ground water level at 28 feet from the surface, and the secondary copper sulphides, chalcocite, and covellite were in evidence near the water table. The primary minerals occur mainly as selective replacements of bedding and of cleavage in the contorted graphitic schist, but chalcopyrite, pyrite, and uraninite have also been found in quartz veinlets intersecting the carbonaceous slates and graphitic schists.

Some of the characteristics of the replacement ore are shown on Figure 2, which gives a downpitch (easterly) view of a minor anticlinal dragfold, the limbs of which have been attenuated by shearing. Chalcopyrite and uraninite occur as selective replacements of certain beds and along cleavage planes.

Exploration is at present proceeding in the primary zone and assaying and geologic mapping of cross-cuts have shown a more uniform distribution of both uranium and copper over a greater width than at the surface. This is partly due to the structure, but also strongly suggests extensive leaching and very localized secondary enrichment in the oxidized zone.

The deposits at Dyson's and White's Extended prospects were obscured and both were found by geophysicists using Geiger-Mueller counters. Costeaning disclosed deposits containing autunite and uranium ochres. Diamond drilling has shown that the secondary uranium minerals persist to 100 feet

vertical depth from the surface and, although pyrite occurs, no primary uranium minerals have yet been encountered. The occurrence of copper minerals is rare at both localities.

At Dyson's prospect the lode occurs in close association with thin beds of carbonaceous slates, which are interbedded with quartzite and limestone. Quartz veins, some of which contain pyrite, are present near the prospect.

Due to poor core recovery and poor outcrop conditions the geology at White's Extended deposit is not yet clear, but the lode appears to occur in a

FIG. 2. Down pitch (easterly) view of minor anticlinal dragfold in carbonaceous slate showing characteristics of primary replacement ore. ×2 natural size.

brecciated zone near the contact of slates and limestone. Quartz veins are also present near the prospect.

The Mt. Fitch prospect, 4½ miles northwest of Brown's prospect, conforms in general characteristics to the White's type of deposit but the Crater type of deposit is unique for the Rum Jungle area.

The Crater prospect, which is situated approximately 3½ miles southeast of White's prospect, and which was discovered by one of the authors (R. S. M.) and geophysicist D. Dyson in 1951, is a type locality for a low-grade radioactive

conglomerate bed occurring in a grit formation of the Brock's Creek Group and known to extend over a distance of about 2 miles. The conglomerate bed is situated a short distance south of junction with the granitic complex, and a major fault of the Giant's Reef system and several minor faults of the system of cross-faults intersect the area.

A mineralogical examination of a sample of the richer part of the conglomerate bed has been carried out, and it has been suggested that the radioactivity is due to detrital radioactive minerals such as zircon, xenotime, and monazite, but the results are not conclusive. Radiation absorption tests suggest that uranium is present, and the occurrence of this radioactive conglomerate bed in an area where hydrothermal uranium deposits are known, suggests that the radioactive minerals may have a hydrothermal rather than a detrital origin.

It is thought that the deposit may represent the leached outcrop of a bed that is richer in uranium minerals in depth. The deposit will be tested by drilling in 1952.

THE MINERALIZATION AND ITS CONTROL.

It has been pointed out in the preceding section that the main uranium prospects occur irregularly along a line trending in a northeasterly direction, and that two types of deposits, namely, copper-rich and the copper-poor types, occur.

Field investigations have shown that an axial plane shear has developed in the dragfold associated with the Giant's Reef faulting, and because this shear follows closely the line of mineralization it is considered by one of the authors (R. S. M.) to have an important bearing on ore deposition. It is expected that it will be displaced similarly to Giant's Reef by the system of cross-faults.

The known uranium prospects occur at irregular intervals but there appears to be some localization near the intersections of the cross-faults with the axial plane shear. Although not shown on the map, a strong cross-fault is believed to occur in the vicinity of Dyson's prospect, but its position has not yet been accurately fixed. The most favorable host rock for both uranium and copper deposition is carbonaceous slate, and it appears that deposition has been by selective replacement of carbonaceous slate beds adjacent to their intersection with the axial plane shear.

Mineragraphic investigations on primary ore from White's prospect [2] have shown that a close association exists between chalcopyrite and uraninite, and that the chalcopyrite has replaced uraninite and must therefore have crystallized later. Available evidence is in favor of a combined uranium-copper mineralization. However, although the copper mineralization is more or less restricted to the slate formation, uranium mineralization persists northeastwards into stratigraphically lower beds (e.g. at Dyson's prospect). The most favorable environment for the deposition of copper minerals throughout the

[2] Stillwell, F. L., Uraninite from East Finniss Deposit, Rum Jungle, N. T.: C.S.I.R.O. Mineragraphic Inv., Special Rept., 1950. Stillwell, F. L., Uraninite from Rum Jungle and Fergusson River: C.S.I.R.O. Mineragraphic Inv., Rept. 473, 1951.

area has been the carbonaceous beds in the slate formation. These have been selectively replaced by the mineralizing solutions, deposition extending for some distance in the beds from their junction with the axial plane shear.

All known uranium prospects occur on the southern side of the axial plane of the dragfold. At White's prospect the deposit occurs as a northeasterly

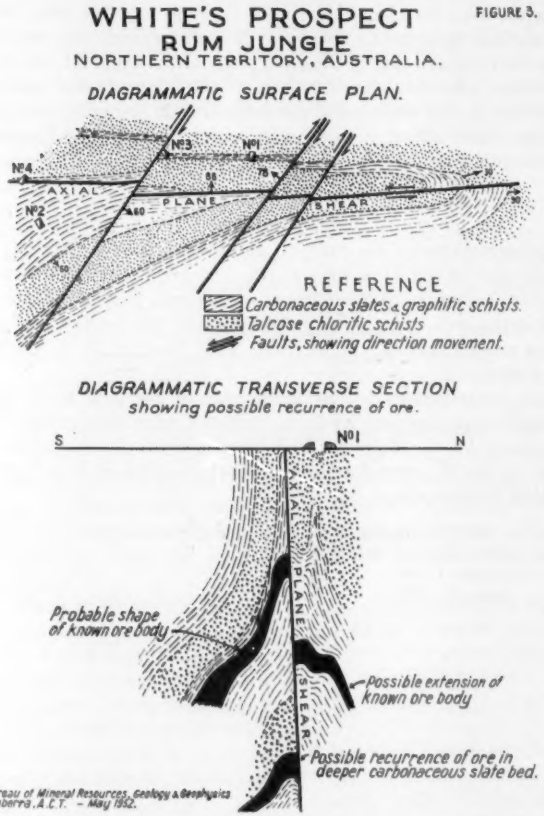


FIG. 3. Diagrammatic traverse section from No. 1 Shaft showing possible recurrence of ore.

pitching truncated arch in carbonaceous slates and graphitic schists adjoining the shear, and available information suggests that similar structural features are present at Brown's prospect and probably elsewhere. Other carbonaceous beds occur in the slate formation, and there are good chances of recurrence of ore deposition where they meet the axial plane shear.

A plan and section at White's prospect showing the geologic structure and the occurrence and possible recurrence of ore appear as Figure 3. The folds on the southern side of the axial plane shear are known to pitch 30 degrees northeasterly, and observations on lineation support this direction of pitch.

At present it appears, particularly at White's and Brown's prospects, that copper minerals have a much wider distribution than uranium minerals, but further exploration may locate lenses of uranium ore that have not been indicated by surface radiometric surveys. No ore occurrences have so far been proved on the northern side of the axial plane of the dragfold, but there appears to be no reason why they should be restricted entirely to the southern side.

In addition to the main axial plane shear it is thought that other parallel shears of the Giant's Reef system occur in the area, and the favorable carbonaceous beds could be mineralized where they intersect the shears.

ACKNOWLEDGMENTS.

This paper represents the authors' interpretation of the geology and nature of mineralization in the Rum Jungle area, and is based on their own work and that of other geologists of the Bureau of Mineral Resources who have done field work in the area, namely, H. J. Ward, (who has worked in the area every field season since 1949), K. W. B. Iten, N. J. Mackay, E. K. Carter, J. Sleis, and D. J. Gates.

Valuable contributions to our knowledge of the field have resulted from mineragraphic investigations by F. L. Stillwell, from mineralogical and petrological work by W. B. Dallwitz; and from mineral determinations and assay carried out by the Western Australian, South Australian, and Northern Territory chemical laboratories.

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS,
COMMONWEALTH OF AUSTRALIA,
CANBERRA CITY,
June 27, 1952.

DISCUSSION

CHEMICALLY PURE GEOLOGESE.

Sir:—Some one has said that a little knowledge is a dangerous thing. Many geologists have too little knowledge of chemistry. These statements are generalizations with which most scientists—indeed most geologists—would agree. The logician might take these statements and conclude that since a little knowledge of chemistry is dangerous, geologists should not place themselves in a precarious position, but should leave chemistry strictly alone. One may follow the logician, in which case he need read no further here.

Let us return to the original premises and see why, in some cases, a little knowledge is dangerous, and how the geologist can avoid this danger. Geologists enjoy an outstanding reputation as semanticists—they have a word for everything and they know exactly what each word means. (The word may mean different things to different geologists—for example, "diabase"—but this fact is of little importance to our argument.) Geologists, being sensitive individuals, are offended when chemists use such hybrid words as "petrochemical" to indicate synthesis of organic compounds from petroleum. The geologist asks: How can this be? Is not "petra" Latin for rock? Obviously "petrochemical" should mean chemicals from rocks, and should include quick lime, hydrated lime, plaster of paris, superphosphates, etc. Certainly it should not be restricted to substances derived exclusively from petroleum. (Incidentally, some geologists use "lime" for calcium carbonate, but this usage is best considered as slang.)

Let us return to geologists and semantics. Some geologists have learned enough about physical chemistry to know portions of the vocabulary. Physical chemistry has a language of its own. It is a very convenient language but it should be treated with caution by strangers, if they wish to avoid embarrassment. (We should blush on asking the waiter for the snout of a bird (bill) when we merely wish to pay our meal check.)

Several expressions have crept into the geologic literature which do not mean to a physical chemist the things that have been included by geologists. For example, "base exchange" (now frequently called "cation exchange") means the interchange of cations between a solid and a liquid at ordinary pressure and temperature conditions. It has nothing to do with two solids interacting; it has nothing to do with hydrothermal alteration or synthesis of silicate minerals. Likewise, unless we are with Alice in Wonderland, it does not involve ordinary double decompositions, nor does it involve dissolution of silicates. In other words, "base exchange" has a restricted meaning in the hands of chemists and there should be no doubt concerning its meaning.

Recently another good word has been borrowed from the physical chemists. We see the phrase "desorption temperature" used to indicate, amongst other things, the decomposition temperature of gypsum. Here then is some fuzzy thinking expressed in very precise terms, because "desorption" has nothing to do with the isobaric thermal decomposition of a crystalline hydrate. Thus, our objections to "desorption temperature" are twofold: Not only is there no desorption, but what does take place does not take place at a fixed temperature except under isobaric conditions.

This communication should end then, like any good sermon, with a plea to geologists. If you wish to borrow the words and phrases of physical chemistry, borrow the conventional meaning at the same time. The former is of little use without the latter, unless one wishes to contribute "chemically pure" geologese.

DUNCAN MCCONNELL.

THE OHIO STATE UNIVERSITY,
COLUMBUS, OHIO,
Sept. 17, 1952.

REVIEWS

The Mineral Resources of the World, Vol. II, Atlas of the World's Resources. By WILLIAM VAN ROYEN AND OLIVER BOWLES WITH COLLABORATION OF ELMER W. PEHRSON. Pp. 181; figs. 186. Prentice-Hall, Inc., New York, 1952.

This large-sized volume, measuring 12 x 15 inches, deals with 29 important mineral commodities, including water power. It is a conspectus of the world situation with respect to mineral output and reserves. Maps and graphs show the main features of the distribution and production, and special maps show some major deposits in detail. The 29 commodities were chosen because of their commercial importance both nationally and internationally.

The chapters and authors are: Preview, by E. W. Pehrson; Coal, by J. A. Corgan, J. A. DeCarlo, and J. A. Vaughan; Petroleum, by J. W. Frey; Water Power, by B. E. Jones; Iron Ore, Manganese, Tungsten, Molybdenum, Vanadium, by P. M. Tyler; Nickel, Platinum-Group Metals, Fluorspar, by H. W. Davis; Chromite, by N. B. Melcher; Bauxite, by H. F. Kurtz; Copper, Mercury, by H. M. Meyer; Lead, Zinc, by R. H. Mote; Tin, Gold, Silver, by C. W. Merrill; Uranium, Radium and Thorium, by A. F. Matthews; Phosphate Rock, Potash, by B. L. Johnson; Sulfur and Pyrites, by G. W. Josephson; Salt, by F. E. Harris; Diamond, Asbestos, by O. Bowles; Graphite, by D. G. Runner; Mica, by J. C. Arundale. Under each commodity are numerous maps depicting world distribution, country distribution, production, individual districts, and charts showing exports, imports, and consumption of major countries. The text matter deals with occurrence, production methods, reduction or beneficiation methods, nationality of control, reserves, physical properties, consumption, prices, and marketing.

The book is a very useful compendium for the student of mineral deposits, for economists, and for professional and business men.

Mines Register, Successor to the Mines Handbook. By JOSEPH ZIMMERMAN, Editor. Volume 24, 1952 edition. Pp. 771. Atlas Publishing Co., New York, 1952. Price, $25.00.

This volume is much thicker than its predecessor Volume 23 that appeared in 1949. It contains the latest information on 7,000 active mining companies in the Western Hemisphere. For each company it gives the location of the mine, history, officers, capitalization, earnings and dividends for several years, description of the property, equipment, production for recent years, ore reserves, and number of men employed. It also lists more than 40,000 inactive mines and their location. The customary special section includes statistical data of the metal industry, company officials, officers, engineers, mining company securities, their exchanges, and price ranges of stocks for 1943 to 1951. A Buyers Guide is also included. The book will continue to serve the useful purposes of its well-known predecessors.

Practical and Experimental Geography. By W. G. V. BALCHIN AND A. W. RICHARDS. Pp. 136; figs. 73. John Wiley and Sons, Inc., New York, 1952. Price, $2.75.

The title of this little book causes wonder as to how geography can be experimental; but a glance through the contents dispels any doubt. It is an original and ingenious book that treats of practical and experimental methods of value to teachers of geography. Profuse diagrams illustrate the procedures.

The book is arranged in five sections. The first, The Earth's Movements and Some Effects, includes experiments and models to demonstrate problems of latitude, longitude; time, seasons, the path of the sun in the sky, phases of the moon, sundials and time wheels. The second section, Land Forms, shows earth sculpture tanks, relief and geological models. The third section, The Atmosphere and the Oceans, contains experimental work and charts illustrating meteorological instruments, models of depressions, wind roses, cold air and katabatic winds, movements of rain belts, and models demonstrating wave action and oceanographic principles. The fourth section deals with Survey and Map projections, and the fifth section, Distribution Maps and Cartograms, outlines the principles involved in the construction of distribution maps and cartograms.

The book certainly will be helpful to all teachers of geography.

Europe, 2nd Edit. By SAMUEL VAN VALKENBURG AND COLBERT C. HELD. Pp. 826; illus. John Wiley and Sons, Inc., New York, 1952. Price, $7.50.

This revision makes its appearance at a time when Europe is very much in the minds of everyone, and its geography is hazy to many. The first edition appeared in 1935 and revision was obviously needed. More than eighty percent of the book has been entirely rewritten or revised and a new junior author has been added. New interpretations of current problems have been added along with new maps and illustrations. The chapters on Germany, Soviet Union and Poland have, of course, been entirely rewritten.

The first 14 chapters deal with general geographic topics relating to Europe as a continent, such as climate, soils and vegetation, use of land and ocean, power and minerals, manufacturing, trade, transportation, peoples and political units, population and the march of civilization. The following 32 chapters deal with the various countries of Europe in which the land forms, climate, resources, regions, activities, transportation and people are discussed.

The book is one that will be referred to by student and layman for knowledge of the countries, people, seasons, and industries of Europe.

Tabellen zur Optischen Bestimmung der Gesteinsbildenden Minerale. By W. E. TRÖGER. Pp. 147; figs. 387; tbls. 17. E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1952. Price, DM 27.80.

This book consists entirely of tables, charts and nomograms of the rock-forming minerals, illustrating their optical properties. The treatment is of water-soluble salts, isotropic, opaque, uniaxial tetragonal, hexagonal and trigonal, and biaxial minerals, followed by tables and charts.

Geography of Living Things. By M. S. ANDERSON. Pp. 202; figs. 5. Philosophical Library, New York, 1952. Price, $2.75.

This little pocket-edition book, printed in small type, deals chiefly with man and his living. After an explanation of what the book is about, there follows Man as

an Animal; Direct Effects of his Environment on Man; Man, Rocks and Water; Man and his Food; The Soil, Pests and Diseases.

BOOKS RECEIVED.

FRANK G. LESURE.

U. S. Geological Survey—Washington, D. C., 1950, 1952.

Tem-165. Preliminary Examination of the Uranium Propect at the Spider No. 1 Claim, Honeycomb Hills, Juab County, Utah. M. H. STAATZ AND H. L. BAUER, JR. Pp. 7; figs. 2.

Circ. 184. Reconnaissance for Radioactive Deposits in South-Central Alaska, 1947–49. ROBERT M. MOXHAM AND ARTHUR E. NELSON. Pp. 14; figs. 4; tbls. 3; pl. 1. *Contains 3 reports. No significant amounts of radioactive material were found.*

U. S. Bureau of Mines—Washington, D. C., 1952.

Min. Mkt. Rept. 2092. Distribution of Oven and Beehive Coke in 1951. PREPARED BY J. A. DECARLO, F. C. SCALF, AND EMMA E. RYAN. Pp. 40; figs. 3; tbls. 6.

Mineral Trade Notes, Vol. 34, No. 6. COMPILED BY FLORENCE E. HARRIS AND MARY E. TROUGHT. Pp. 64.

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1951–52.

Rmo-909. Investigation of Uranium Deposits near Sanastee, New Mexico. ROBERT F. DROULLARD AND EVERETT E. JONES. Pp. 7; fig. 1. *Brief description of carnotite deposits in Recapture sandstone member of Jurassic Morrison formation.*

Rmo-910. Investigation of Thucholite Deposits near Placerville, Colorado. GEORGE E. MOREHOUSE. Pp. 13; figs. 4; tbls. 5.

Rmo-911. Uranium Deposits on Southwest Rim of Lukachukai Mountains, Northeast Arizona. JOHN A. MASTERS. Pp. 10; fig. 1; pl. 1. *Ore-grade uranium deposits shown to be channel controlled in cross-bedded sandstone.*

Rmo-913. Uranium in Fall River Area, Clear Creek County, Colorado. LOREN E. SMITH AND KENNETH E. BAKER. Pp. 12; fig. 1; pls. 4.

Rmo-924. Annual Report for July 1, 1951 to June 30, 1952. Part 1. A Geologic Guide to the Marysvale Area. PAUL F. KERR, GERALD BROPHY, HARRY M. DAHL, JACK GREEN, AND LOUIS E. WOOLARD. Pp. 57; figs. 14. *Petrology, rock alteration, and mineralogy of area. Origin of uranium believed related to magmatic sources.*

Twelfth Semiannual Rept. Pp. 125. *Activities in Atomic Energy Program, January–June, 1952.*

Structural Geology. MARLAND P. BILLINGS. Pp. 456; pls. 19. Prentice-Hall, Inc., New York, 1952. Price, $6.25. *The 8th printing (August, 1952) of a well-known text and reference book reprinted on thinner paper.*

Sedimentary Petrography, with Special Reference to Petrographic Methods of Correlation of Strata, Petroleum Technology and other Economic Applica-

cations of Geology, Reprint of 3rd Edition of 1940. HENRY B. MILLER. Pp. 638; figs. 100; pls. 52. Thomas Murby & Co., London, 1952. Price, $9.50. *This is a report of the 3rd edition that appeared in 1950, the only change apparently being a new corrigenda which points out that many of the British standards and references are superseded by later ones.*

Bibliography and Index of Geology Exclusive of North America, Vol. 16. MARIE SIEGRIST, MARY C. GRIER, AND MARCIA LAKEMAN. Pp. 462. Geol. Soc. America, New York, 1952. *Covers literature outside of North America published in 1951 and material prior to 1951 not previously cited.*

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SOCIETY OF ECONOMIC GEOLOGISTS

ABSTRACTS OF PAPERS TO BE PRESENTED AT THE JOINT MEETING OF THE SOCIETY OF ECONOMIC GEOLOGISTS AND THE GEOLOGICAL SOCIETY OF AMERICA, TO BE HELD AT BOSTON, MASSACHUSETTS, NOVEMBER 13–15, 1952.

SOME ASPECTS OF THE GEOCHEMISTRY OF URANIUM.

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New abundance of uranium data based upon analytical results from the University of Wisconsin demonstrates the soundness of the uraniferous province concept for common rock types. British workers also report uraniferous provinces in which all rock types tend to be higher in uranium content. Until the distribution and extent of uraniferous provinces are well known, it will be difficult to arrive at average abundance figures for common rock types. Aside from the province concept other difficulties arise in sampling and analytical errors.

Radiometric and fluorimetric analyses showed that thorium tends to be separated from uranium in the sedimentary cycle. This is believed to be caused by the oxidation of U^{+4} to U^{+6}, perhaps in the form of UO_2^{+2}. This oxidation proceeds at a potential somewhat less than the oxidation of Fe^{+2} to Fe^{+3}. The uranyl ion is much different in charge and radius from Th^{+4} and would tend to become separated from it. The presence of iron in the ferrous state is probably a good indication that any uranium present is in the tetravalent state, and in this state it is diadoch with Th^{+4} and Zr^{+4}. This last conclusion is supported by the fact that thorium and uranium are usually associated in plutonic rocks, and these rocks have much of their iron in the ferrous state.

The uranium content of volcanics has received special attention, and it seems to be governed first by the general content of the province and second by the silica content. These conclusions are only tentative, however. Most pyroclastics are unique among primary rocks in that they have a very large surface area that makes them particularly susceptible to leaching. The role of this leachability in the geochemistry of uranium is under study.

PITCHBLENDE DEPOSITS ON QUARTZ HILL, CENTRAL CITY DISTRICT, GILPIN COUNTY, COLORADO.

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The Central City district, in the northern half of the Colorado Front Range mineral belt, has been the principal domestic source of pitchblende. A recorded 110,757 pounds of U_3O_8 has come from Quartz Hill—more than 98 per cent from the Wood and Kirk mines.

Quartz Hill is underlain by a folded sequence of Precambrian biotite granite gneiss, amphibolite, quartz-biotite schist, granulite, and skarn intruded by pegmatite, metagabbro, and Upper Cretaceous bostonite. These rocks are cut by steeply

dipping, east-trending faults that contain metalliferous veins. The Central City district is zoned with pyritic gold ores in the center and lead-zinc-silver ores on the periphery. Quartz Hill is on the west side of the district and is in a transition zone where the mineralogy of the veins changes from quartz-pyrite-gold on the east to quartz-pyrite-sphalerite-chalcopyrite-galena-gold-silver on the west. Pitchblende occurs with chalcopyrite in this transition zone. Gold ore bodies are grossly controlled by the intersection of faults with brittle granitic layers, and pitchblende ore bodies probably have a similar control. Mineralogically and structurally the veins are of xenothermal type.

Ore produced from the Wood and Kirk mines had an estimated average grade of 0.2 per cent U_3O_8. Unmined parts of the Wood and Kirk veins within the transition zone probably contain ore of similar grade.

STATUS OF SUMMARY COAL RESOURCE SURVEYS NOVEMBER 1952.

PAUL AVERITT.

U. S. Geological Survey, Washington, D. C.

Summary studies of coal resources are in preparation or in press covering seven States—Illinois by the Illinois Geological Survey; and Indiana, Virginia, Colorado, North Dakota, South Dakota, and Oklahoma, by the U. S. Geological Survey. Like other such statewide studies completed in recent years, these studies show a continuation of the trend toward a reduction of the estimates of original reserves.

Based on the latest available figures for individual States, the original coal reserves of the United States total about 2 trillion tons as compared with M. R. Campbell's estimate of 3.2 trillion tons. This difference is due primarily to the more conservative method used in preparing the new State estimates, which are on a bed-by-bed basis as contrasted with Campbell's regional basis.

The total original reserves in the United States thus appear to grow successively smaller as the new conservative State summary studies are completed. Because many of the newer State estimates are rock-bottom, minimum estimates based on incomplete data, it is apparent that the total United States reserves, when finally appraised at the conclusion of the current program, will be the minimum known reserves, and the figure will be subject to increase as mapping and exploration are continued.

PUNCHED-CARD BIBLIOGRAPHY FOR COAL.

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Within recent years the literature concerned with coal has grown so rapidly that it has become difficult to assemble and correlate the available information. In an effort to organize in the most easily accessible form a large amount of data with regard to the geological, biological, and chemical factors active in the formation of coal, along with information on the analysis and structure of coals and components of wood, a hand-sorted punched card file has been prepared. The preparation of the code for the cards will be discussed, and the use of the cards will be demonstrated.

The excellent bibliography on coal which was recently distributed by Mr. Horace Miller should serve as a starting point for future work. Several methods will be proposed by which it is hoped that the scope of an annual bibliography on coal can be expanded to include such subjects, among others, as mining and product preparation. The advantages of an annual bibliography prepared jointly by a group of

interested persons and presented in a form where facts can be correlated is very appealing. Several suggested working methods will be proposed for the use of punched cards in a co-operative program.

HISTORY AND CAUSES OF RISING WATER LEVELS IN THE RECHNA DOAB, PUNJAB, WEST PAKISTAN.

CHARLES W. CARLSTON.

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In a study conducted under the auspices of the Food and Agriculture Organization of the United Nations and the Government of Pakistan, the writer studied the ground-water conditions of the Rechna Doab in the Punjab. Here a high water table over much of the Doab is contributing to deterioration of agricultural lands through salt accumulation.

The sediments underlying the Doab are typical river deposits of the Indus system consisting of coarse to fine sand, silt, and lenticular clay beds, capped by a generally continuous silt and clay deposit up to 40 feet thick. A range of old hills of Archean rocks projects through the sediments at three points in the Doab.

The ground-water table of the Doab began rising in 1882, when the first irrigation canal was opened. In a large area of the central part of the Doab, where the water table was, in general, 30 to 80 feet below the land surface in 1882, ground-water levels are now within 10 feet of the surface. Where the water table in 1882 was 80 to 96 feet below the land surface, the water table is still 20 to 33 feet below the land surface, but is rising at the rate of 1.5 to 2 feet per year.

Maps of the water table in 1920 and 1950 indicate that the principal cause of rising ground-water levels is seepage from unlined canals. Infiltration of irrigation water also contributes.

SUMMARY OF TWO CONFERENCES ON PROBLEMS OF DUNKARD STRATIGRAPHY AND RESULTING INTERPRETATION.

AUREAL T. CROSS.

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The ideas and opinions expressed at the Field Conference "On the Stratigraphy, Sedimentation and Nomenclature of the Upper Pennsylvanian and Dunkard Strata" and at the Round Table Conference in Washington are summarized and contrasted. The interpretation of these suggestions as integrated with the specific problems encountered in the area under consideration is given.

The entire sequence of strata is divided into cyclothems, and several cyclothems are grouped as a formation. The position of the base of the coal-top of the underclay is the dividing line between successive cyclothems. A number of Dunkard and Monongahela coal seems may be correlated on the basis of plant microfossils, and a number of examples of the results of this work are illustrated.

Additional information now available for the southern part of the Dunkard Basin is given. This includes especially the great increase in percentage of the total thickness of rock of the red shale component of the cyclothems and in facies of this type; most of the members of the cyclothems gradually disappear until red shales and impure sandstones occupy virtually the entire thickness. In such areas cyclothems are difficult to ascertain and virtually impossible to differentiate on the basis of any information or characters now available. Intervals from persistent coals are the only evidence found useful at present.

CONCENTRATION OF MINOR AND TRACE ELEMENTS IN ASH OF LOW-RANK COALS FROM TEXAS, COLORADO, NORTH DAKOTA, AND SOUTH DAKOTA.

MAURICE DEUL AND C. S. ANNELL.

U. S. Geological Survey, Washington, D. C.

As part of the routine geochemical investigations of coal, 282 lignite samples from seven areas were analyzed spectrographically. C. L. Waring and C. S. Annell of the Geological Survey developed the method used for the semiquantitative estimation of 68 elements in one exposure of a 10-mg sample.

B, Ba, Sr, Pb, Ti, P, and Mn are present in concentrations as high as 0.1 to 1.0 per cent in most of the areas; As, V, Mo, Zr, Zn, Ni, Co, Be, and Y are present in similar concentrations in fewer areas. Cu, Cr, Sc, Ga, Ge, Li, and La are present in concentrations as high as 0.01 to 0.1 per cent; Yb is present as high as 0.001 to 0.01 per cent; and Ag was not found in concentrations higher than 0.001 per cent.

There are unusually high concentrations of Pb, Sn, Sr, Mo, Co, B, and La in many of the coal ashes analyzed. The trace-element content is given for ashed lignite from each of the seven areas.

URANIUM DEPOSITS IN THE BLACK HAWK DISTRICT, GRANT COUNTY, NEW MEXICO.

ELLIOT GILLERMAN.

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Pitchblende occurs in association with native silver and with nickel and cobalt arsenides and sulphides in the old Black Hawk district, 14 miles west of Silver City, New Mexico. The geologic setting is similar to that of the high-grade uranium deposits at Great Bear Lake, Canada, and at Joachimstahl, Czechoslovakia; and the mineralogical associations in the three localities are almost identical. In geologic setting and in mineralogical associations the Black Hawk deposits are unique in the United States. The Black Hawk district produced high-grade silver from 1881 to 1893, but the mines have been idle since that time and are at present inaccessible.

The ore is in fissure veins with a carbonate gangue in Precambrian quartz diorite gneiss. The veins trend north to northeast; and the deposits that contain radioactive minerals form a northeast-trending belt about 2 miles long. This belt parallels the elongation of a nearby monzonite porphyry stock. Most of the major deposits are along faults in the gneiss, adjacent to where the faults cut monzonite porphyry dikes or apophyses of the main stock. Diamond drilling to test the area for commercial deposits of uranium, nickel, and cobalt is in progress.

*DETERMINATION OF RANK IN COAL BY DIFFERENTIAL-THERMAL ANALYSIS.**

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Accurate determinatins of the rank of coal ranging from lignite to meta-anthracite have been obtained using inexpensive conventional D.T.A. equipment commonly utilized in the study of clay. Sharp endothermic peaks indicating loss of volatile components exhibit sufficient variation for demarcation of rank. The use of vacuum or inert atmospheres is not required.

Results indicate the rank of coal depends on the structural organization of the coal as well as the amount and nature of volatile constituents. Boundaries between ranks are essentially in agreement with A.S.T.M. specifications. A complete gradational series was not observed. Breaks occurred between meta-anthracite and anthracite, medium-volatile bituminous and high-volatile bituminous, and at the boundary of subbituminous B coals.

The thermal curves can be correlated with Gieseler plasticity measurements and graphically indicate the region where physical changes occur with increasing temperature. Thermal curves of lower-rank coals change with time, caused by accelerated oxidation of the powdered sample. The change is gradual and progressive and introduces reproduction difficulties. Coals of medium volatile and higher rank change much more slowly and are reproducible.

IRON DEPOSITS OF THE CONGONHAS DISTRICT, MINAS GERAIS, BRAZIL.

PHILIP W. GUILD.

U. S. Geological Survey, Washington, D. C.

The Congonhas district, in the southwest corner of the iron region of central Minas Gerais, has been mapped by the U. S. Geological Survey in co-operation with the Brazilian Departmento Nacional da Produção Mineral. Large hematite deposits occur in the "Itabirite formation", the middle member of the Proterozoic(?) Minas series, a sequence of quartzites, schists, phyllites, ferruginous sediments, and carbonate rocks. Itabirite is a finely laminated rock composed essentially of quartz and iron oxides, chiefly hematite, that in places contains dolomite and amphibole. It is believed to represent metamorphosed chemical precipitates. Moderate deformation and uplift in post-Minas time preceded erosion and the deposition of quartzite and itabirite debris in conglomerates of the overlying Itacolumi series. Severe post-Itacolumi deformation folded and thrust faulted rocks of both series. Ultramafic intrusions antedate the orogeny; granodiorites and allied types are younger.

Local enrichment of the iron formation produced masses of high-grade ore (68–70 per cent Fe). Tight folds and breccia textures preserved in hard ore suggest that enrichment was post-deformation, but a moderate to strong cleavage, caused by orientation of the micaceous specularite, indicates that replacement preceded the close of the orogeny. Because many deposits occur at points of structural irregularity it is postulated that enrichment was contemporaneous with deformation and that severe stress may have played a part in localizing the deposits. As there is also evidence that some hematite ores resulted from replacement of dolomite breccia, a combination of structural and mineralogic factors probably controlled their formation.

*GEOCHEMICAL PROSPECTING IN THE BLACKBIRD COBALT DISTRICT, IDAHO.**

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During the 1951 field season, the U. S. Geological Survey conducted an experimental geochemical-prospecting study in the Blackbird cobalt district, Lemhi County, Idaho. The purpose was to determine whether the distribution of minor amounts of cobalt and copper in soil could be correlated with the distribution of cobaltite ore. More than 1800 samples of soil and stream sediment were collected and analyzed for

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cobalt and copper by rapid chemical methods developed by Hy Almond of the Geological Survey. The data of this investigation show that: (1) the mean cobalt content of soil outside the mineralized district is 20 ppm (parts per million); and (2) within an area of about 2 square miles enclosing almost all the known cobaltite occurrences of the district, the mean cobalt content of the soil is 100 ppm. The amount of cobalt within the anomalous area, in excess of that over unmineralized ground, is in the order of 1000 times the amount of cobalt in all the known deposits, when both amounts are expressed as tons per foot of depth. The cobalt content of soils over known cobalt ore ranges from 200 ppm to 1000 ppm. Trenching on the basis of geochemical data uncovered a zone strongly mineralized with cobaltite in a previously unexplored and unknown area. In some parts of the area studied, the variation in copper content parallels the variation in cobalt content; elsewhere the cobalt and copper patterns appear to be independent. The content of cobalt and copper in stream sediment closely reflects the content of those metals in the soils in the drainage basin upstream.

HYDROTHERMAL GEOCHEMISTRY OF MAGNETITE—PROGRESS REPORT.

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Measurements in progress on the solubility of magnetite in water at temperatures to 500°C and 1000 bars show up to 0.002 per cent Fe in solution. To avoid oxygen contamination, distilled water was boiled and swept with Seaford nitrogen. The water was either loaded into the open Morey bomb under a current of nitrogen, or introduced through the pressure-gauge capillary after evacuation and flushing with nitogen. Upon completion of a run the solution was condensed from an opening in the pressure-gauge capillary, and immediately analyzed for Fe^{++} and Fe^{+++} with ortho-phenanthroline in a photoelectric colorimeter. By using long narrow cuvettes, and micro-quantities of concentrated solutions of purified reagents, the sensitivity was extended to 0.00005 per cent Fe with only 2 ml of sample.

Stainless steel bomb walls contaminate solutions with iron, which even penetrates sheet silver liners, necessitating bored liners of nonferrous alloy.

Investigations have begun on: (1) agitation to reduce the week's time now required for equilibrium, (2) analysis for H_2 in gas phase of the sample, (3) effect of pH on solubility, and (4) conversion of $Fe(OH)_2$ to magnetite under hydrothermal conditions.

ALTERATIONS AND URANIUM MINERALIZATION, MARYSVILLE, UTAH.

PAUL F. KERR, GERALD P. BROPHY, HARRY M. DAHL, JACK GREEN, AND LOUIS E. WOOLARD.

Columbia University, New York, N. Y.

Alteration zones containing a sequence of clay minerals, silicification, alunitization, or pyritization occur in a variety of rock types in an area of about 50 square miles at Marysvale, Utah. Two field seasons with intervening laboratory study have been devoted to an analysis of the relationship between the alteration and uranium mineralization. More significant channels of alteration have been mapped.

The area has been mapped to establish correlation between the alteration and rock types. The major geologic units, such as the Bullion Canyon volcanic series, the Mount Belknap volcanics, and the intrusives have been subdivided for greater

clarity in structural interpretation, interpretation of the alteration, and the delineation of host rocks presumably favorable to the deposition of uranium.

Alteration appears to diminish in the Mount Belknap red facies. Minor bleached areas occur along faults and shear zones. These are characterized by the development of adularia but contain few clay minerals. Such zones traced into bordering rocks of the Bullion Canyon volcanic series or intrusives may show enlargement and the development of argillic alteration.

Uranium-bearing veins contain both oxidized uranium minerals and uraninite. Fluorite is a common associate becoming darker near ore zones. Jordisite and ilsemannite are associated vein minerals. Montmorillonite, hydromica, and kaolinite are common clay mineral constituents of the uranium vein walls. Localized hematitic alteration may be observed. Biotite may develop as an alteration mineral. Brecciated thin quartz veins, pyritic and chloritic zones, and occasionally magnetite zones occur in the uraninite area.

Uranium minerals have been found in several units of the Bullion Canyon series accompanied by zones of argillic alteration. The principal veins found, however, are in quartz monzonite or fine-grained granite. The Mount Belknap has not yet yielded more than migratory secondary mineralization along fractures. Alunitic zones are generally free from uranium, but uranium mineralization is occasionally found near by.

Conclusions presented constitute a progress report on the Marysvale Alteration Study jointly sponsored by the Division of Raw Materials, Atomic Energy Commission, and the Department of Geology, Columbia University.

RELATION OF PITCHBLENDE DEPOSITS TO HYPOGENE ZONING IN THE FRONT RANGE MINERAL BELT, COLORADO.

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The distribution of pitchblende deposits in several Front Range mining districts shows a distinctive relation to the pattern of hypogene zoning. The deposits appear to be restricted to an intermediate or transitional zone between central areas of pyritic gold veins and peripheral areas of silver-lead-zink veins. At present we do not know whether pitchblende is more common in the inner or the outer part of the intermediate zone. In at least one district (Central City) significant quantities of copper in the form of chalcopyrite have been produced from the intermediate zone. The position of uranium in an intermediate zone between gold and zinc was tentatively implied by W. H. Emmons (1926) in his generalized treatment of hypogene zoning.

At least seven local geologic factors must be considered in interpreting the zonal distribution of Front Range pitchblende deposits: bostonite intrusives, fault patterns, multiple stages of uranium mineralization, differences between paragenetic sequence and position of minerals in successive zones, correlation of pitchblende with copper sulfides (and sulfosalts?), scale and complexity of zoning in plan and in section, and effective depth of mineralization. The significance of some of these factors can already be evaluated.

The concept of the position of pitchblende in hypogene zoning is developed to stimulate and guide the systematic search for pitchblende deposits. Though the zonal position of pitchblende deposits is best known for areas of complex base-metal mineralization dominantly of mesothermal (possibly xenothermal) character, knowledge of the zonal position of uranium deposits in widely different geologic environments might be similarly useful in a search for ore.

MINERALIZATION AND ROCK ALTERATION IN THE ELIZABETH COPPER DEPOSIT, VERMONT.

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The Elizabeth copper deposit is located in Orange County, approximately 10 miles west of the Connecticut River. It is in the southern end of the "Vermont Copper belt" in the western portion of the Green Mountains. It is a hydrothermal replacement predominantly in a favorable stratigraphic horizon. The country rock is chiefly mica-garnet schist with thin quartzite beds. A key horizon is an amphibole rock, containing common green hornblende, carbonate, quartz, and feldspar. The favorable ore horizon is a tremolite-phlogopite-carbonate rock, probably originally a limestone bed in the siliceous sediments.

The main ore minerals are pyrrhotite and chalcopyrite associated with minor amounts of sphalerite, pyrite, galena, molybdenite, and cubanite. The most important gangue minerals are tourmaline, rutile, and idocrase. Post-ore faults are filled by calcite, pyrite, and quartz.

Sericitization is dominant in the north end and down the northerly plunge of the ore body. It is associated with slight silicification. To the south the silicification is more pronounced. Adjoining the ore a zone up to 1 foot wide consists of fine-grained quartz and albitic feldspar. The hornblende of the regional amphibolite has been altered to biotite forming rosettelike pseudomorphs. In the host rock tremolite has been altered to phlogopite and talc. Feldspar shows a slight saussuritization. In addition there is an increase in silica.

URANIUM ORE CONTROLS IN THE HAPPY JACK MINE AND VICINITY, WHITE CANYON, UTAH.

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Channels within the Triassic Shinarump formation are thought to be the primary uranium ore control in White Canyon, southeastern Utah. This has been demonstrated in the Happy Jack Mine and on the Sunrise and Gonaway claims. In addition, there are important intrachannel controls; the most conspicuous are carbonaceous matter and lithologic changes.

Shinarump stream channels were first mapped in White Canyon during 1951, on the basis of outcrop mapping alone. Three of these channels—the Happy Jack, Sunrise, and Gonaway—were later explored and extended by drilling. Detailed geologic mapping of the Happy Jack mine and drill-hole information supplemented each other.

A structural contour map of the base of the Shinarump, corrected for regional dip, was the most important tool in locating ore. Each drill site was located only after the preceding diamond-drill core information had been evaluated and placed on the contour map. Forty-five per cent of the holes drilled were situated in ore, resting on or near the bottom of channels. No ore was found in this area outside of channels. Correlations among diamond drill holes and outcrops reveal that the ore is characteristically in a porous carbonaceous sandstone on top of Shinarump siltstone.

Cross sections of the Happy Jack mine show, in addition to the above features, horizontal bedding-plane control for pitchblende and sulfide mineralization. There is no evidence for vertical control of primary ore.

PITCHBLENDE DEPOSIT AT THE CARIBOU MINE, BOULDER COUNTY, COLORADO.

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Pitchblende occurs at the Caribou mine in a mesothermal carbonate vein that contains silver lead and zinc minerals. Unlike most of the large, well-known pitchblende deposits of the world, it does not contain nickel- and cobalt-bearing minerals. The deposit is believed to be unique in that the host rock is a Tertiary monzonite. The pitchblende is in a tension fracture (the Radium vein) of an interconnecting vein system, at vertical depths between 875 and 1075 feet. Two pitchblende ore shoots are known; the largest one has a vertical dimension of 200 feet and a horizontal dimension of 70 feet. Within the ore shoots, pitchblende forms a discontinuous seam as much as 6 inches thick along the side of sulfide veins. The sulfides and the pitchblende are not intergrown. There is no apparent difference in mineralogy, other than the presence of pitchblende, between the pitchblende-bearing vein and the other veins in the system. The pitchblende is predominantly a soft, sooty variety, but the larger masses also contain a hard, botryoidal variety. The soft pitchblende is believed to have been deposited later and at a lower temperature than the hard pitchblende.

EFFECT OF CARBON DIOXIDE ON THE SOLUBILITY OF SOME SUBSTANCES IN SUPERHEATED STEAM AT HIGH PRESSURES.

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Geophysical Laboratory, Washington, D. C.

An apparatus has been constructed which makes it possible to study the gaseous solubility of substances in a mixture of about 94 per cent water and 6 per cent carbon dioxide at temperatures up to 600°C. and pressures up to 2000 bars. The corrosive character of this mixture introduces some experimental difficulties, which have largely been overcome. The presence of carbon dioxide affects the gaseous solubility of all substances tried.

GEOLOGIC PROBLEMS OF THE SOUTHEAST MISSOURI LEAD BELT.

ERNEST L. OHLE.

c/o St. Joseph Lead Company, Bonne Terre, Mo.

This paper is essentially a progress report on the geological study being made in the southeast Missouri District by the St. Joseph Lead Company. The problems encountered are described together with an assessment of the progress toward their solution. These problems have consisted of the subdivision of the Bonneterre formation into units that can be mapped underground, the recognition of the structural controls of the ore trends, the recognition of the types of rock alteration accompanying or preceding ore deposition, and the collection of data which may indicate the method of ore genesis.

The Bonneterre formation is divided into eight principal zones which are numbered from top to bottom. Contacts between zones are mapped, and structural features are indicated by contouring. Ore in each zone has distinctive characteristics.

Buried Precambrian igneous knobs have localized some ore bodies in the Lead Belt area, but sedimentary arch structures of depositional origin are the out-

standing features controlling ore trends. Fracture zones exerted a secondary influence where arches are present and, where arches are absent, were the dominant ore-controlling structures.

Major alteration effects are dolomitization of limestone, "fingering" and spotting, recrystallization, and removal by solution. Glauconite and adularia have been introduced or redistributed.

Lateral migration of the ore solution was important, and the vertical component of motion almost surely was up rather than down. The marginal position of sphalerite in the galena ore bodies is in accord with the relative solubilities of the two sulphides.

MINERALOGY AND PETROLOGY OF THE MANGANESE DEPOSITS OF AROOSTOOK COUNTY, MAINE.

LOUIS PAVLIDES AND CHARLES MILTON.

U. S. Geological Survey, Washington, D. C.

Syngenetric manganese occurs in sedimentary rocks of Ordovician (?) and Silurian age in Aroostook County, Maine, as two distinct types: (1) in bedded hematitic deposits in which braunite is the principal manganese mineral; and (2) in siliceous carbonate rocks in which ferroan rhodochrosite of variable composition is the principal managanese mineral. In the bedded hematitic deposits the braunite occurs as impure laminae and less commonly as impure nodules. Manganese carbonates, including rhodochrosite, are also associated with the hematitic deposits. In the siliceous carbonate rocks the ferroan rhodochrosite is in laminae composed largely of that mineral or in laminae containing abundant chlorite.

Minor manganese minerals consist of spessartite, rhodonite, bementite, pyrophanite, stilpnomelane, neotocite, and many inconclusively identified minerals some of which give x-ray patterns suggesting manganoan chlorite and talc. Other minerals in these deposits are quartz, feldspar, sericite, chlorite, muscovite, apatite, barite, phlogopite, calcite, dolomite, pyrite, pyrrhotite, and magnetite.

Occurrence, distribution, and paragenesis of some of the manganese minerals are discussed, and chemical analyses of rocks and minerals, with x-ray and spectrographic data, are given. Comparison is made with deposits of similar mineralogy that have been described elsewhere.

WIDESPREAD OCCURRENCE AND CHARACTER OF PITCHBLENDE IN THE TRIASSIC AND JURASSIC SEDIMENTS OF THE COLORADO PLATEAU.

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During the last three years numerous uranium deposits in the sedimentary rocks of the Colorado Plateau have been shown to contain pitchblende. Although this mineral is not restricted to any one formation, most of its occurrences are in the lower Chinle and Shinarump formations (Triassic). There are two principal modes of occurrence of pitchblende, one with sulfides of copper, the other in asphaltic bodies. In both types, association with fossil plants or occurrence in beds rich in organic debris is generally the rule. Fossil plants replaced by pitchblende and sulfides show remarkable preservation of the organic structures. Pitchblende generally replaces cell walls, while the copper sulfides fill the cells, as is shown particularly well at White Canyon, Utah. Under these conditions the hardness and reflectivity of the pitchbende may differ considerably from that of hydrothermal vein

pitchblende. At Seven Mile Canyon, Utah, in addition to replacing wood, pitchblende rims quartz and limestone pebbles. The ores of Temple Mountain, Utah, contain pitchblende as minute grains, 1–10 microns in diameter, arranged in ribbon or ellipsoidlike aggregates in asphaltite. It is likely that not all the uranium occurs as pitchblende, but that a portion is combined with the organic matter. The paragenesis of the minerals is complex and somewhat obscure, but formation of the pitchblende contemporaneous with, or shortly followed by, copper sulfides is suggested. In the asphaltite deposits a polymerization by alpha particles of light hydrocarbons may be involved.

*ORIGIN OF THE CHROMITE DEPOSITS OF THE BAY OF ISLANDS IGNEOUS COMPLEX, NEWFOUNDLAND.**

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The Bay of Islands complex forms a discontinuous belt of layered ultrabasic and gabbroic rocks along the west coast of Newfoundland. The basal ultrabasic zones of the plutons, which are as much as 4 miles thick, are composed of undifferentiated enstatite and forsterite. These zones are overlain by banded gabbroic rocks. The two rock types are interbanded at their contacts and are parts of the same intrusion.

Chromite deposits occur near the top of the ultrabasic zone, below the ultrabasic-gabbro contact. Coarse-grained clinopyroxenite (diopside) is found near the chromite horizon and nowhere else in the ultrabasic zone. Feldspar (now hydrogrossular) is found in the ultrabasic rocks near the chromite deposits. In the interbanded gabbroic and ultrabasic zone, spinel is occasionally found forming rims around anorthositic lenses in feldspathic dunite. These rims appear to be the result of reaction between ultrabasic and feldspathic materials. It appears that the presence of lime and alumina is favorable to the concentration of chromite into a chromite mineral deposit.

The formation of spinel by the interaction of olivine and anorthite has been proven experimentally by Anderson (1915), and the subsequent conversion of spinel to chromite has been described by Bowen (1928). It is concluded that this reaction explains the localization of chromite deposits near the top of the ultrabasic zone below the overlying banded gabbroic rocks. At the same time, the reaction of lime with the ultrabasic magma has caused the formation of the *diopside* bands found near the chromite deposits.

A similar relation of chromite deposits to gabbro contacts is found in the Bird River sill of Manitoba and in the Camagüey complex of Cuba. This relation may be more common than previously suspected and, where found, is a valuable guide to prospecting.

IRON-ORE DEPOSITS OF LIBERIA.

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Geologic investigations in Liberia from 1944 to 1952 have revealed two distinct types of bedrock iron deposits: (1) low-grade itabirite, and (2) replacement bodies of medium- to high-grade ore.

Well-layered itabirite consisting mainly of quartz combined with magnetite or hematite or both and averaging 30 to 40 per cent Fe, is widely distributed in Liberia. Large masses several miles long and many hundreds of feet thick form or cap the highest mountains in the country. The itabirite ranges from fine-grained fer-

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ruginous slate to well-crystallized granular rock containing magnetite grains up to a quarter of an inch across. Bedded quartzite is associated with the itabirite in two major deposits, leaving little doubt as to their sedimentary origin.

All high-grade ore is associated with folds in medium- to coarse-grained itabirite. Although the itabirite has been locally hydrothermally enriched in many steeply dipping homoclinal masses, all known major high-grade ore bodies are related to crests or troughs of folds. The large ore bodies in Bomi Hill are believed to have been formed mainly by replacement of itabirite lenses and to a lesser extent by replacement of quartz-plagioclase-mica-garnet gneisses, with which the itabirite is interlayered in a relatively open irregular basin. The main iron mineralization was preceded or accompanied by formation of skarn rich in cummingtonite and anthophyllite, epidote, hornblende, and dark mica, with accessory pyroxene and spinel, all of which have been extensively altered to chlorite and serpentine minerals. Layered ores of good milling grade include recrystallizd itabirite, itabirite in which quartz has been replaced mainly by cummingtonite, and magnetite-cummingtonite-quartz rocks formed by replacement of gneiss along closely spaced shear planes.

PETROGRAPHIC ANALYSIS OF A COLUMN SAMPLE AND OF RUN-OF-MINE LIGNITE FROM ZAP, MERCER COUNTY, NORTH DAKOTA.

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Microscopic analysis of North Dakota lignite for anthraxylon, opaque and translucent attritus, fusain, and mineral matter yields information of potential importance to mining and utilization of this coal. Methods of analysis which employ macroscopic examination of surfaces of coal are relatively useless for this reactive substance. Paleobotanical information is especially valuable for lignitic coal and should be used to expand the knowledge gained from purely petrographic studies.

A series of thin sections of a 10-foot column from Dakota Collieries Mine, Zap (Fort Union Formation), was studied. There is a marked concentration of opaque attritus in the upper 4.5 feet. Analysis of a series of thin sections made from a carefully selected representative sample of lumps of stoker size run-of-mine lignite from the mine gave results very close to the overall percentages for the column.

A method for analysis of samples of small particles of lignite was devised in which a crushed representative sample of lignite is embedded in plaster, thin sections made with the usual polishing techniques, and these sections then studied in the same manner as those from a column. This method makes possible petrographic study of a representative portion of a crushed sample prepared for chemical analysis. Analysis of such a representative sample of run-of-mine coal is more meaningful to utilizers of the mined coal than are analyses of column or core samples, though these are necessary to establish the distribution of constituents within the bed.

GEOGRAPHIC AND STRATIGRAPHIC DISTRIBUTION OF PENNSYLVANIAN COAL IN THE UNITED STATES.

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Pennsylvanian coals are restricted to areas east of the Rocky Mountains except for minute quantities in the Sangre de Cristo and Sandia Mountains of Colorado and New Mexico. Maps will show their abundance and geographic variation with reference to six stratigraphic subdivisions designated as the Springer, Morrow, Lampasas, Des Moines, Missouri, and Virgil. Coal occurs in greatest thickness,

24 feet, in the Springer in the Pocahontas field, Virginia-West Virginia; 67 feet in the Morrow in the Cahaba field, Alabama; 91 feet in the Lampasas in western Virginia; 112 feet in the Des Moines in the southern anthracite field, Pennsylvania; 72 feet in the Missouri in the southern anthracite field, Pennsylvania; and 28 feet in the Virgil in southwestern Pennsylvania. Variations are shown (1) in total coal thickness, (2) in frequency of coal beds, (3) in percentage of coal in the total column; and in relation between coal total thickness and the following ratios: (4) clastic-nonclastic, (5) sandshale, and (6) marine-nonmarine sediment ratio.

Coal and marine sediments have inverse relations. Coal is largely restricted to areas with high clastic-nonclastic ratio. Relations between coal variation and total sediment thickness are inconsistent, as shown by great coal thickness in the geosynclinal section of western Virginia and also in the moderately thin craton section of central western Indiana.

Analysis of data for this paper was made with the co-operation of Miss Margaret Parker, who set up the data on I.B.M. cards.

STRUCTURAL CONTROL IN THE VERMONT COPPER DISTRICT.

WALTER S. WHITE.

U. S. Geological Survey, Washington, D. C.

The copper deposits of Orange County, Vermont, are lenticular bodies of more or less massive pyrrhotite with minor amounts of chalcopyrite. Their wall rocks are mica schists, calcareous schists, and amphibolites of probable Ordovician age. The ore deposits were probably formed in late Devonian time.

The broad arch in the schistosity dominates the regional structure. The copper district is a north-trending belt on the eastern flank of this arch. Both the schistosity and the arch were formed by differential upward flowage of the rocks in the crestal area. Undeformed porphyroblasts of kyanite, staurolite, and locally sillimanite in the rocks of the copper district show that the thermal peak of metamorphism followed most of this deformation.

Further slight deformation of the already schistose rocks provided the openings or potential voids for the introduction of the sulfides. This final movement consisted in a rise of rocks on the east relative to rocks on the west. At the Ely mine, the sulfide veins and lenses lie parallel to schistosity on the short limb of a broad open roll in the schistosity; the ore shoot follows the axis of the roll. In the Elizabeth deposit, which lies along a fault plane, the most spectacular ore shoots occur where the schistosity is conspicuously deranged by drag on the fault. Some of the gangue minerals, notably andesine, garnet, and hornblende, indicate that the rock temperature was still high at the time the ore was deposited.

SCIENTIFIC NOTES AND NEWS

WILLIAM H. BURGIN is now a field engineer for the Kennecott Copper Corp. with headquarters in Denver, Colo. He formerly was mining engineer for the Geneva Steel Co. at Provo, Utah.

F. J. PETTIJOHN, professor of geology at the University of Chicago, has completed field work in the Menominee Range, Michigan area, which he had been doing for the U. S. Geological Survey.

W. B. HOOVER, of Albuquerque, was elected president of the New Mexico Geological Society at the society's 6th annual convention held in Socorro.

The KANSAS GEOLOGICAL SOCIETY held its 16th Regional Field Conference in West Central and Southwest Missouri October 10, 11, and 17, 18. This conference was held with the co-operation of the Missouri Geological Survey.

JOHN HALL has been appointed assistant professor of geology at Western Reserve University, Cleveland, Ohio. He has been with the Ohio State Geological Survey since last October.

Effective August 1, 1952, THOMAS L. KESLER has been appointed senior geologist of the Tennessee Coal & Iron Division of U. S. Steel, with headquarters at Jefferson City, Tenn.

MORGAN J. DAVIS, president of the A.A.P.G., announces the report of the nominating committee, with the following candidates for executive offices of the association for 1953–54: for president, JOHN EMERY ADAMS, Standard Oil Co. of Texas, Midland, Texas, and JESSE V. HOWELL, consulting geologist, Tulsa, Okla.; for vice-president, GLENN C. CLARK, Continental Oil Co., Oklahoma City, Okla., and LESLIE M. CLARK, Pacific Petroleums, Ltd., Calgary, Alberta, Canada; for secretary-treasurer, CLARENCE E. BREHM, consulting geologist, Mt. Vernon, Ill., and ELLIOTT H. POWERS, Southern Production Co., Fort Worth, Texas; for editor of the association's monthly Bulletin of Petroleum Geology, GEORGE V. COHEE, U. S. Geological Survey, Washington, D. C., and ARMAND J. EARDLEY, University of Utah, Salt Lake City, Utah.

BENJAMIN WEBBER, U. S. Geological Survey, left Washington for service abroad as project chief on a Point IV mission to Iraq, Secretary of the Interior Oscar L. Chapman announced.

ROBERT M. DREYER has been granted a leave of absence from his duties as professor of geology at the University of Kansas to accept a position as geologist in charge of the uranium division of Kerr-McGee Oil Industries. Professor R. C. MOORE will assume the departmental chairmanship.

LEON W. DUPUY, mining engineer, is the new coordinator of mineral resources studies for the U. S. Bureau of Mines, Washington, D. C. Mr. Dupuy was formerly special assistant, Region VI of the Bureau, Amarillo, Texas.

THOMAS P. THAYER, U. S. Geological Survey, in recognition of his work on the geology of the Bomi Hills iron deposits, Liberia, was made a commander of the Star of Africa. Order was conferred by President Tubman.

PETER JORALEMON, Park City, Utah, has been named a director and superintendent of mines for New Park Mining Co., Utah.

ANNAN COOK, with Kennecott Copper Corp.'s exploration department, New York, N. Y., has been appointed district geologist for the east.

W. D. JOHNSTON, JR., chief, Foreign Geology Branch, U. S. Geological Survey, was made an officer in the Order of the Southern Cross in recognition of his geologic work in Brazil.

WARREN E. FISHER, Ishpeming, Mich., head of the geologic department of Inland Steel Co., has resigned to join Kennecott Copper Co., as field engineer.

RALPH C. HOLMER, formerly teaching at Colorado School of Mines, has joined the exploration staff of Kennecott Copper Corp., New York, N. Y., as chief geophysicist.

H. C. BURRELL, chief geologist of the exploration party which made the Cerro Bolivar discovery in Venezuela, has been appointed manager of raw materials development for Columbia-Geneva Steel Division of U. S. Steel Co., with headquarters in San Francisco, Calif.

JOHN ELLIOT ALLEN, head of the geology department, college division, of the New Mexico Institute of Mining and Technology, is head of a survey party to study and map the geology of 450 sq. mi. in the Navajo Indian reservation under a U. S. Bureau of Indian Affairs contract.

HENRY E. REED, JR., has been appointed assistant geologist for the mineral development department of the Great Northern Ry. Co., Willison, N. Dakota.

JOSEPH F. BROWN has joined the Grand Junction Exploration Branch of the U. S. Atomic Energy Commission as a geologist.

THOMAS P. ANDERSON, mining engineer and geologist, has resigned from the Raw Materials Division of the U. S. Atomic Energy Commission where he was assistant chief of the Denver Exploration Branch. He will enter private practice in Golden, Colo.

SAMUEL S. GOLDICH, geologist for the U. S. Department of the Interior's Geological Survey, is in the Pocos de Caldas area in Minas Gerais, Brazil, making a reconnaissance examination of bauxite deposits. Dr. Goldich's examination, similar to other Point IV examinations made in Brazil in the past, is being conducted in cooperation with geologists from the Departamento Nacional da Producao Mineral.

L. A. S. RITSON, Professor of Mining at the Royal School of Mines has been elected President of the Institution of Mining and Metallurgy and will take office at the General Meeting to be held on May 28, 1953.

ROBERT M. DREYER, geology department chairman, has been granted a leave of absence from the University of Kansas to be geologist in charge of the uranium division for Kerr-McGee Oil Industries. Professor R. C. Moore will take Professor Dreyer's place.

BENJAMIN N. WEBBER, senior geologist with the U. S. Geological Survey in Phoenix, New Mexico, is in Iraq making a 3 month survey for the Technical Cooperation Administration.

THOMAS W. OSTER, chief of the Grand Junction (Colorado) exploration branch of the U. S. Atomic Energy Commission, has been transferred to Canberra, Australia, as chief of the mission which will advise and assist the Australian government in the exploration and development of uranium deposits.

RICHARD C. BOGUE and GUS H. GOUDARZI, Geological Survey technicians, are now on route to the Middle East where they will assist in developing a minerals exploration program in Saudi Arabia along a planned extension of a railway line from Riyadh to Jidda on the Red Sea.

The Society of Economic Geologists held a business meeting and a dinner in Algiers, on the occasion of the meetings of the 19th International Geological Congress. At the dinner, the Penrose Gold Medal of the Society of Economic Geologists was awarded to Professor P. F. FOURMARIER of Liège University, Belgium.

DWIGHT M. LEMMON, of the U. S. Geological Survey, has been assigned to Iran, in response to requests received by the Department of State from the government of Iran, for TCA, Point IV assistance. It involves a 3 month reconnaissance to make a quick assessment of mineralized areas, existing mining industry, equipment, facilities, local technical manpower available for expansion of present industry, and determination of which known mineral commodities should receive first consideration for exploration, development or utilization; to act as a technical adviser to the Iran government and to the Country Director in the United States State Department, in shaping a minerals program of of technical assistance; and to aid in the selection of young Nationals from Iran who might benefit as recipients of in-service trainee grants in the United States. He expects to be in the Near East until January 1953.

HAROLD KIRKEMO has resigned as geologist in the Exploration Department of the Anaconda Copper Mining Company and has joined the U. S. Geological Survey.

VINCENT P. GIANELLA, chairman of the Department of Geology-Geography, has retired after 29 years of teaching at the Mackay School of Mines, University of Nevada. His work will be taken over by LON S. MCGIRK, JR.

GLEN L. WATERMAN has been appointed chief geologist of the Chile Exploration Company, Chuquicamata, Chile.

HAROLD E. CULVER has been appointed to the Mutual Security Agency staff, assigned to the Philippines for 2 years. He is to aid in the rehabilitation of the Department of Geology at the University of the Philippines.